Georgetown: Climate Change

Mitigation Assessment

Report prepared for the Inter-American Development Bank

Final Report

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Executive Summary

This report provides the results of the Climate Change Mitigation Assessment that has been undertaken for the captial city of Guyana – Georgetown. This study is one of a series of baseline studies for Georgetown, forming part of the Inter-American Development Bank's (IDB) Emerging and Sustainable Cities Initiative. The studies have been developed under the IDB's technical cooperation agreement with Guyana's Central Housing and Planning Authority, titled "Climate Resilience Support for the Adequate Housing and Urban Accessibility Program in Georgetown, Guyana" (GY-T1137).

Following the recent discovery of offshore oil and gas, it is likely that Georgetown will undergo a period of rapid development. It has the opportunity to act now by making strategic long-term decisions on the direction of future urban development, supported by oil and gas revenues, to minimise future energy consumption and associated greenhouse gas (GHG) emissions. This will also bring about considerable co-benefits such as reducing air pollution, encouraging active travel and improving energy security.

The Mitigation Assessment has three main components:

1. Compilation of a baseline GHG inventory for Georgetown for 2016;
2. Development of a business as usual GHG projection for Georgetown at five yearly intervals out to 2040; and
3. An assessment of GHG mitigation actions that could be taken up under 'feasible' and 'smart' scenarios. These cover the transport, energy generation, energy efficiency and waste sectors.

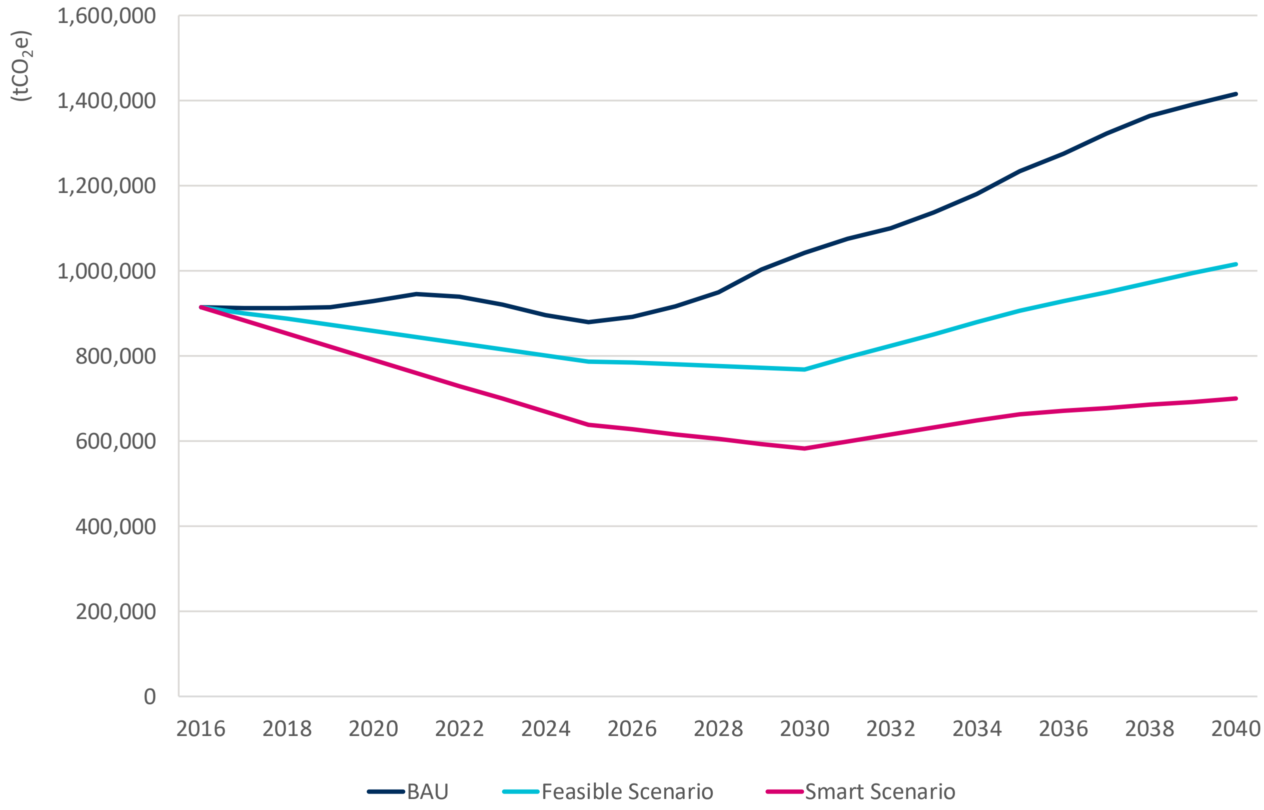
The approach to quantifying the GHG emissions baseline inventory is based upon the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*, which is generally accepted as the most comprehensive and internationally accepted methodology for city and community scale inventories. The following direct GHGs have been considered: carbon dioxide, methane and nitrous oxide. Total emissions for Georgetown are estimated to be 915 ktCO_2e or 6.6 tCO_2e per capita. Estimates reveal that the dominant source of emissions in Georgetown is the stationary energy sector, which accounts for 67% of total emissions.

To inform the emission scenarios, projections of both the population and economic activity in Georgetown were made, explicitly considering the impact of oil. Taking the Georgetown GHG inventory for 2016 and applying the anticipated GDP and population growth projections, the 'business as usual' GHG emissions by sector can be calculated. It is estimated that emissions will increase by 14% by 2030 and 55% by 2040 from a 2016 baseline.

A priority list of mitigation actions was identified through stakeholder consultation with local ministries and organisations, and an initial assessment of the GHG mitigation potential and the feasibility of implementation. For each action a 'feasible' and 'smart' option was considered and the associated GHG emissions savings, costs and co-benefits assessed.

Figure 1 demonstrates that under the feasible and smart scenarios, GHG emissions in Georgetown could be up to 28% and 52% lower in 2040 respectively. Georgetown's emissions are expected to reach over 1.4 MtCO_2e by 2040. The collective impact of all mitigation actions in 2040 could be as high as 0.4 MtCO_2e in the feasible scenario and 0.7 MtCO_2e in the smart scenario. From 2020 to 2040, this equates to a reduction in cumulative GHG emissions of 4.6 MtCO_2e and 8.5 MtCO_2e respectively.

Figure 1 GHG emissions in Business as Usual, Feasible and Smart Scenarios



Note: BAU: Business as usual
Source: Aether; Vivid Economics

The largest emission savings were found to come from rooftop solar PV, energy from waste, fuel switching and optimising the public transport system. Collectively, the four top measures account for over 300 ktCO$_2$e in 2040 in the feasible scenario and over 500 ktCO$_2$e in the smart scenario. Mirroring the emission savings, rooftop solar PV and optimising the public transport system have the highest up-front capital costs. Many measures however have relatively low capital costs, particularly those that reflect a change in operational practices with little associated investment.

In the feasible scenario, 8 out of the 14 measures, equal to 15% of BAU emissions (217 ktCO$_2$e) in 2040, have a negative abatement cost over the 20-year timeframe considered. A negative abatement cost occurs when the money saved each year in operational expenditure outweighs the initial capital investment. The lowest abatement costs are seen in rooftop solar hot water systems, LEDs in buildings and optimising the public transport system.

In the smart scenario, 6 of the 14 measures totalling 23% of BAU emissions (332 ktCO$_2$e) come at negative abatement cost. These include solar PV and hot water systems, LEDs in buildings, optimising the public transport system and cycle lanes. Fuel switching at the Kingston power plant, waste separation and energy from waste generate additional abatement of 23% of BAU emissions at less than USD 20/tCO$_2$e. This means in total Georgetown can reduce roughly 47% of BAU emissions (660 ktCO$_2$e) in 2040 at low or negative abatement cost.

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Glossary

BAU	Business As Usual
CH&PA	Central Housing and Planning Authority
CH_4	Methane
CIRIS	City Inventory Reporting and Information System
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
ESCI	Emerging and Sustainable Cities Initiative

EV	Electric vehicle
GHG	Greenhouse Gas
GDP	Gross Domestic Product
GEA	Guyana Energy Agency
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GPL	Guyana Power and Light
GSDS	Green State Development Strategy
IDB	Inter-American Development Bank
Km	Kilometres
KW	Kilo-Watt
LEDs	Light Emitting Diodes
MACC	Marginal Abatement Cost Curve
mph	Miles Per Hour
MSW	Municpal Solid Waste
MT	Million Tonnes
MW	Mega Watt
NDC	Nationally Determined Contribution
N_2O	Nitrous oxide
PAHO	Pan-American Health Organization
PP	Power Plant
PV	Photo-voltaic
SEER	Seasonal Energy Efficiency Ratio
SHW	Solar Hot Water
SUTS	Sustaiinable Urban Transport Study
UoG	University of Guyana
USD	United States Dollar

1 Introduction

1.1 Background

The city of Georgetown now stands at a critical juncture. With the discovery of offshore oil and gas, Guyana stands to go through a period of rapid and unprecedented growth and transition. The influx of finance and demand for new infrastructure associated with the fossil fuel industry will drive rapid change. Investment decisions made now could 'lock in' the city's development trajectory for the next twenty to thirty years, a time period which will be absolutely critical in terms of the global effort to reduce greenhouse gas (GHG) emissions and to prepare locally for the impacts of near-term climate change.

Georgetown (and the whole of Guyana) has the potential to use revenues from oil and gas to shift from a traditional development pattern to a low carbon, resource efficient approach. Actions which mitigate GHG emissions can bring a host of co-benefits including improved social cohesion, improved health, energy independence, improved air quality, improved mobility, more access to green space and improved resiliency.

Georgetown's emission profile is such that by targeting a few key sectors, significant emission (and financial) savings can be made, while vastly improving the quality of life for all the citizens of the city.

1.2 About this Study

This study is one of a series of baseline studies for Georgetown, forming part of the Inter-American Development Bank's (IDB) Emerging and Sustainable Cities Initiative (ESCI). The studies have been developed under the IDB's technical cooperation agreement with the Central Housing and Planning Authority (CH&PA), "Climate Resilience Support for the Adequate Housing and Urban Accessibility Program in Georgetown, Guyana" (GY-T1137). The following three studies were produced for Georgetown:

- **Climate Change Mitigation Assessment,** to analyse Georgetown's carbon footprint and help the city identify concrete options to reduce this.
- **Disaster Risk and Climate Change Vulnerability Assessment,** to better understand the risks the city faces from natural hazards, including increasing hazardous risk due to climate change, and facilitate adequate planning to reduce these risks and the city's vulnerability.
- **Urban Growth Study**, which assesses the urban footprint of the city and its dynamics under expected future trends, to inform and facilitate successful infrastructure and environmental planning at the city and regional level.

This Climate Change Mitigation Assessment aimed (i) to establish a GHG emission baseline (i.e. GHG inventory) for Georgetown for the year 2016 and (ii) identifying priority GHG mitigation options and consider various future emission scenarios for the city. Three scenarios are considered:

- A 'business as usual' model, based on projected economic and population growth projections with no consideration for emissions reduction interventions. This scenario extrapolates current regional and urban growth trends.
- A 'feasible scenario', incorporating projected economic and population growth projections but including lower cost, lower ambition emissions reduction interventions. This scenario reflects an intermediate growth pattern that differs from the business as usual scenario by proposing strategic policies and interventions to improve sustainability and lower emissions. It is expected to be more feasible than the smart scenario by taking financial, technological, and other constraints into account.

- A 'smart scenario', incorporating projected economic and population growth projections but including higher cost, higher ambition emissions reduction interventions. This scenario reflects an ideal growth pattern characterized by medium to high density, mixed-use development that seeks to improve quality of life and the city's negative impact on the environment (ecological footprint), without taking into account financial or technological constraints.

These scenarios depict potential future emissions pathways for Georgetown and are based on a list of scaled measures to reduce the city's GHG emissions and provide other economic, environmental and social benefits. Potential measures were identified from policy documents including both the Low Carbon Development Strategy (LCDS) and the forthcoming Green State Development Strategy (GSDS) as well as discussions with Government Ministries and other public stakeholders regarding their project pipelines and ambitions for the future. A subset of measures were taken forward for quantitative analysis based on their GHG mitigation potential, feasibility and expected co-benefits. Approximate costs for each action are estimated and the various potential 'co-benefits' discussed. Finally, using all the information and data presented, some key conclusions and recommendations are provided.

For the purpose of the GHG inventory and mitigation actions, the administrative boundary of Georgetown[1] is used as the geographical focus. Thus, emissions generated or caused by activities outside of this boundary (i.e. in the 'Greater Georgetown' area) are not included in this study (with the exception of some transboundary issues relating to transport and waste management described in the GHG inventory report). Emissions resulting from the use of grid electricity within Georgetown are based on the national grid emission factor. Further details of the specific GHG emissions calculations are provided in the following section.

[1] Note this differs for the other components of the 'Climate resilience support for the adequate housing and urban accessibility program in Georgetown' project

2 Georgetown Greenhouse Gas Inventory: 2016

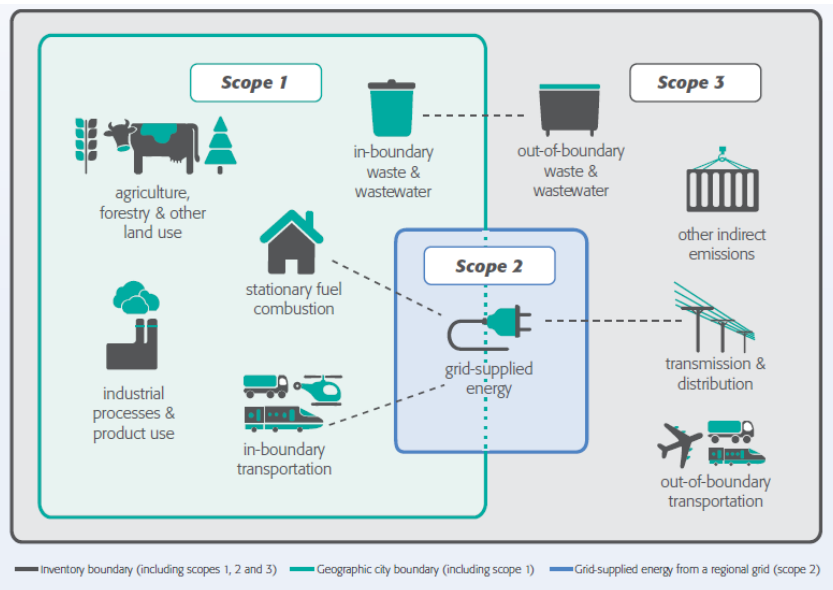
A brief summary of the GHG inventory compiled for Georgetown is presented in this chapter. The full report is provided in Appendix A.

2.1 Methodology

The approach to quantifying the GHG emissions baseline inventory is based upon the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GPC)[2], which is generally accepted as the most comprehensive and internationally accepted methodology for city and community scale inventories. The emission sources included in the GPC are approach are summarised in Figure 2. The figure shows the three 'scopes' of GHG emissions which can be included in GHG inventories at the city scale:

- Scope 1: refers to all emissions which are physically arising within the geographical boundary of the city (e.g. through stationary combustion);
- Scope 2: refers to emissions which are arising outside of the geographical boundary of the city but for which the city is directly responsible (i.e. consumption of grid supplied electricity); and,
- Scope 3: refers to emissions which are arising outside of the geographical boundary of the city but for which the city is indirectly responsible (e.g. emissions occurring outside the city from transporting people/goods to or form the city).

Figure 2 Sources and boundaries of GHG emissions included in the GPC



Source: Aether; Vivid Economics

To inform the calculations to generate the GHG inventory, data and information was collected from a range of local sources following stakeholder consultation meetings held in October 2018. During this process there was broad consensus that the most recent year for which reliable and accurate data was available would be 2016 and so information for that year was collected to serve as the baseline. Estimates for each of the 'Scope 1' emissions sources were made for 2016, except for 'agriculture, forestry and other land use' and 'industrial processes and product use' which were determined to be negligible sources in the context of the

[2] https://ghgprotocol.org/sites/default/files/standards/GHGP_GPC_0.pdf

Georgetown municipal boundary. In addition, 'Scope 2' estimates for grid-supplied electricity were also calculated and scope 3 emissions arising from the international airports were also estimated on the basis that these emissions only arise because of the existence of Georgetown.

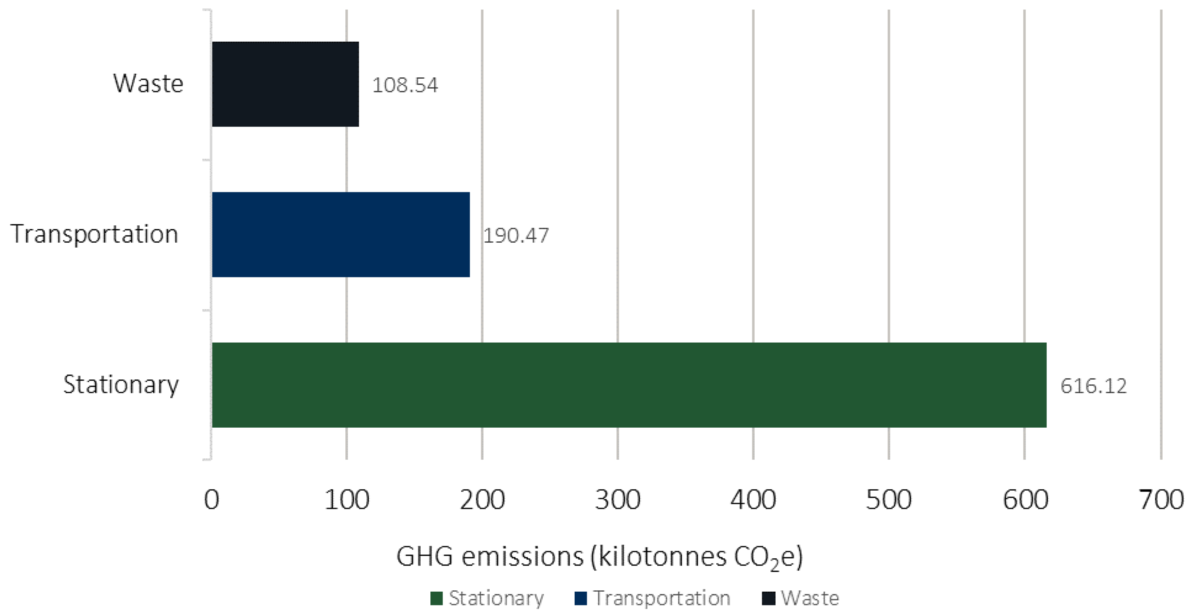
In order to compile the GHG inventory in a useful format which can be easily updated in the future, the *City Inventory Reporting and Information System* (CIRIS) tool/template was used[3]. It is an intuitive template supported by publicly available training and guidance.

2.2 2016 GHG Inventory for Georgetown

The following direct GHGs have been considered: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Emission estimates compiled for Georgetown are presented in the inventory report by sector (Stationary[4], Transportation, Waste). Total emissions for Georgetown are estimated to be 915 kt CO_2e or 6.6 tonnes of CO_2e per capita. Estimates reveal that the dominant source of emissions in Georgetown is the stationary energy sector, which accounts for 67% of total emissions.

Figure 3 Estimated GHG emissions for Georgetown in 2016



Source: Aether; Vivid Economics

In compiling the inventory, a number of assumptions had to be made and these are documented by sector and are typically a result of limited local data being available. Recommendations for improvements to the inventory have been made on a sectoral basis and can be summarised in many cases by the need to find additional Georgetown specific data sources.

[3] The CIRIS tool was developed by C40 specifically for use in generating city-scale GHG inventories (https://resourcecentre.c40.org/resources/reporting-ghg-emissions-inventories)

[4] The stationary sector includes residential, commercial/institutional, manufacturing industries and energy industries. The transport sector includes road transport and aviation.

3 Business as Usual Scenario

3.1 GDP and Population Projections

3.1.1 Context

Currently available long-term demographic and economic projections for Guyana do not take account of the impact of oil production and hence, were not suitable for our scenarios of future growth. Over the next five years, Guyana is set to become the largest global producer of oil in per capita terms. This will have significant and permanent impacts on Guyana's population and economy however, there are not yet studies that estimate what this impact will be in the long term. UN DESA's World Population Prospects assume fertility and mortality will follow long-term trends while migration will remain constant. The IMF only projects real GDP growth for the next five years. To accurately project the future growth of Georgetown, a clear understanding of how oil will impact both demographic and economic trends is critical.

To meet this need, we undertook a series of original forecasts explicitly accounting for the anticipated impact of oil production on Guyana, and Georgetown in particular. This formed an additional analytical output under the ESCI framework, specific to Georgetown. The overall objective was to project future urban land use demand to directly inform the projections of future urban growth under the Urban Growth Study of Georgetown, a separate publication in the same ESCI series (see Section 1.2). To calculate future land use demand, we first projected its core drivers: (i) fertility, (ii) mortality, (iii) net migration, (iv) urbanisation and (v) GDP. From this, we developed a picture of future population and GDP, which both directly inform emission projections under this study. We then combined these projections with an understanding of their relationship with land use demand in Guyana to forecast future land use demand. Please see Appendix C for a more detailed discussion of our approach.

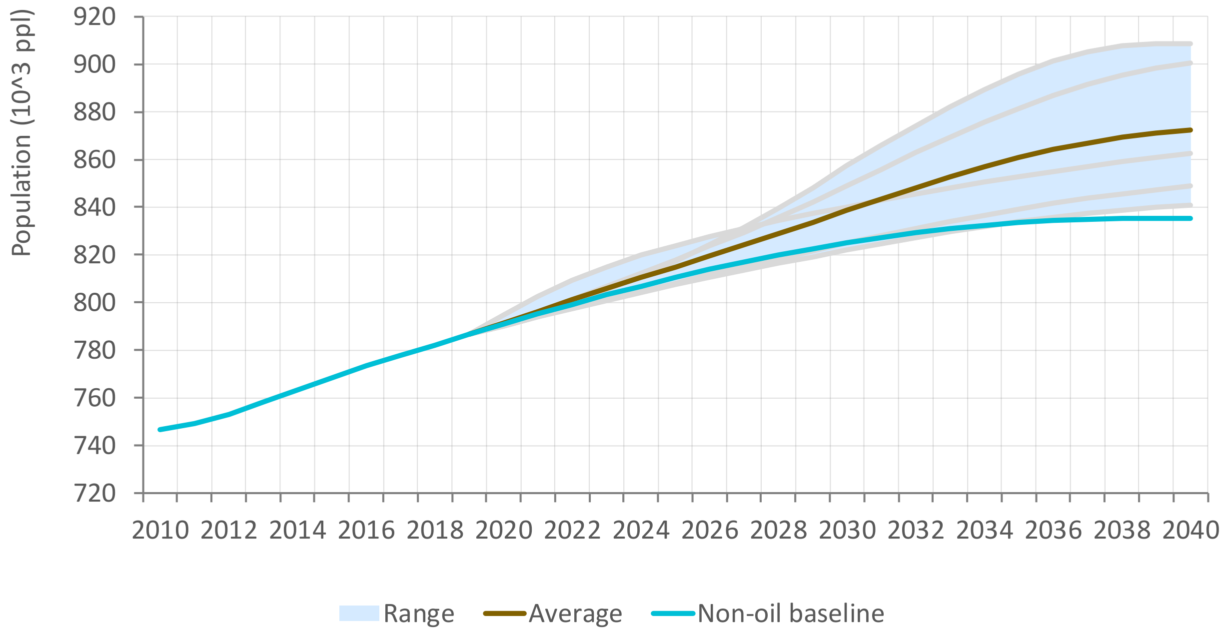
The projections are based on the experiences of five oil-producing countries in the 20 years post oil-discovery creating a range of possible scenarios. These were Angola, Equatorial Guinea, Ghana, Kazakhstan and Oman. For each of the core drivers of land use demand listed above, we examined whether and how long-term trends changed after discovering oil. Each case study country experienced a sizeable and sudden increase in oil production and was selected to capture different possible models of development that Guyana could follow. For example, some countries chose to develop downstream oil and gas sectors while others focussed on direct exportation of crude oil.

The results for each of these scenarios are presented below, alongside the average which is taken as our central projection. Without a clear view on how Guyana will manage its oil industry and the Government's official policy position, it is sensible to consider the full range of possibilities. Averaging across our range provides an objective and holistic assessment of these.

3.1.2 Demographics and urbanisation

Between today and 2040, the population of Guyana is expected to grow by 12%, as detailed in Figure 4. The turquoise line in the figure represents historical data and the projection of what the population would be in the future without the production of oil (the non-oil baseline). The light grey lines represent results from each of the case study country scenarios described in the section above. The light blue area represents the range across these scenarios, while the dark grey line represents the average, taken as our central projection and used to project GHG emissions. The central projection sees a rise in population from 787,000 in 2019 to 872,000 in 2040. The steepest rise occurs over the next 10 years, after which the rate of increase gradually falls. In the highest growth scenario (at the top of our range), Guyana's population increases by 17% relative to today to reach 908,000 in 2040.

Figure 4 The national population is expected to rise by 12% in the next 20 years



Note: Light grey lines represent results from each of the case study country scenarios described in Section 3.1.1 above. These inform both the range and average presented in the chart.

Source: Vivid Economics

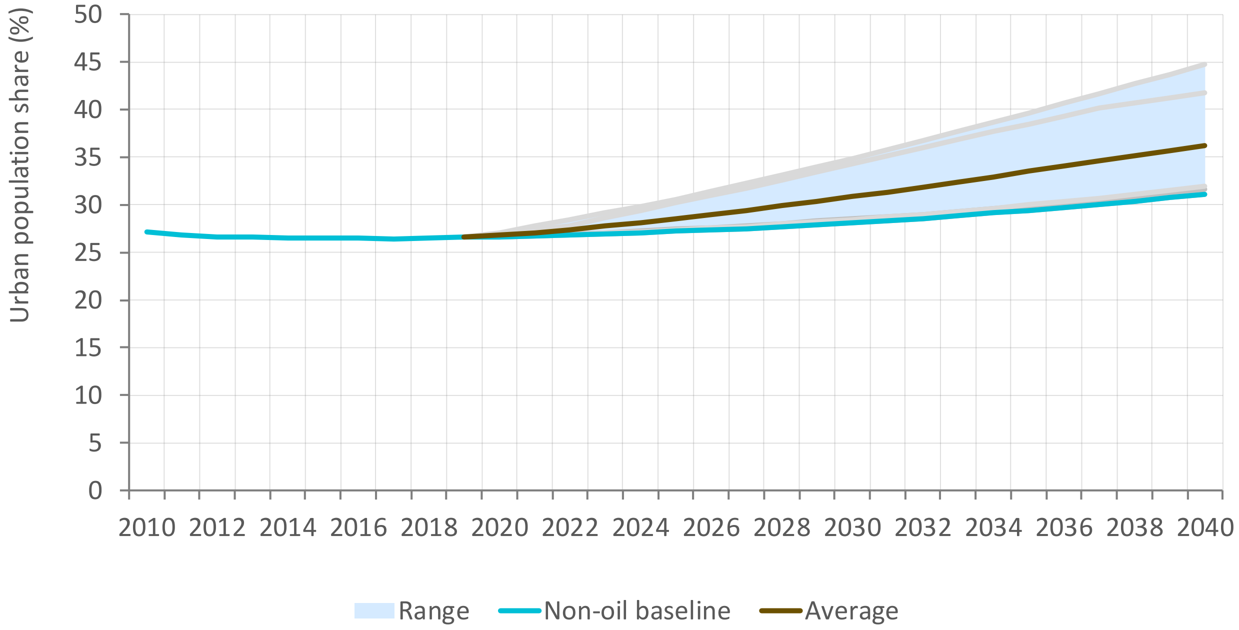
Crude mortality rates rise from 8.5 deaths per thousand people in 2019 to 9.2 deaths per thousand people in 2040. Rising mortality is driven by Guyana's ageing population and masks decreasing trends in age-specific mortality across all age groups. In 2019, mortality rates are estimated at 16.5, 15.5 and 180 deaths per thousand people for the 0-14, 15-49 and 50+ age groups respectively. By 2040, these rates are expected to decrease to 11, 12 and 155 respectively. As we move towards 2040, the 50+ age group accounts for a larger share of the population raising the overall crude mortality rate. Guyana has achieved most 'easy' gains with respect to infant mortality and the vast majority of improvements are seen in the prevention and treatment of disease among the elderly.

Crude fertility rates (births per thousand people) fall out to 2040. In 2019, it is estimated there are roughly 20 births per thousand people in Guyana. This reduces steadily over the time period to reach 15 births per thousand people in 2040. This is largely due to changes in family planning decisions as a result of decreased mortality rates. As parents are increasingly confident that their children will survive to adulthood, they choose to have less.

Net migration increases substantially across the period but remains negative. In 2019, roughly 6 people per thousand leave Guyana each year. This rate falls over the time period, reaching its lowest at 2 people in 2032, and then rising again to 4 people by 2040. This pattern is typical of countries post oil-discovery. Net migration first rises as there is an influx of foreign workers to help with the construction and initial operation of oil extraction. This tapers out over time and net migration rates return to close to their pre-discovery levels. In four out of five of our case study countries, net migration rates remained above our non-oil baseline projections by 2040.

Recent muted trends in the urban share of the population are expected to reverse with current levels rising significantly to 36% by 2040. The urban population share in Guyana has been idling around 26% for the last ten years. This trend reverses in all scenarios, however, oil is expected to substantially increase the pace of urbanisation. Without the impact of oil, the urban share rises by 4% to 31% in 2040. With the impact of oil, the urban share rises by 9% to 36% in 2040.

Figure 5 The urban share is expected to rise dramatically from 26% in 2019 to 36% in 2040



Note: Light grey lines represent results from each of the case study country scenarios described in Section 3.1.1 above. These inform both the range and average presented in the chart.

Source: Vivid Economics

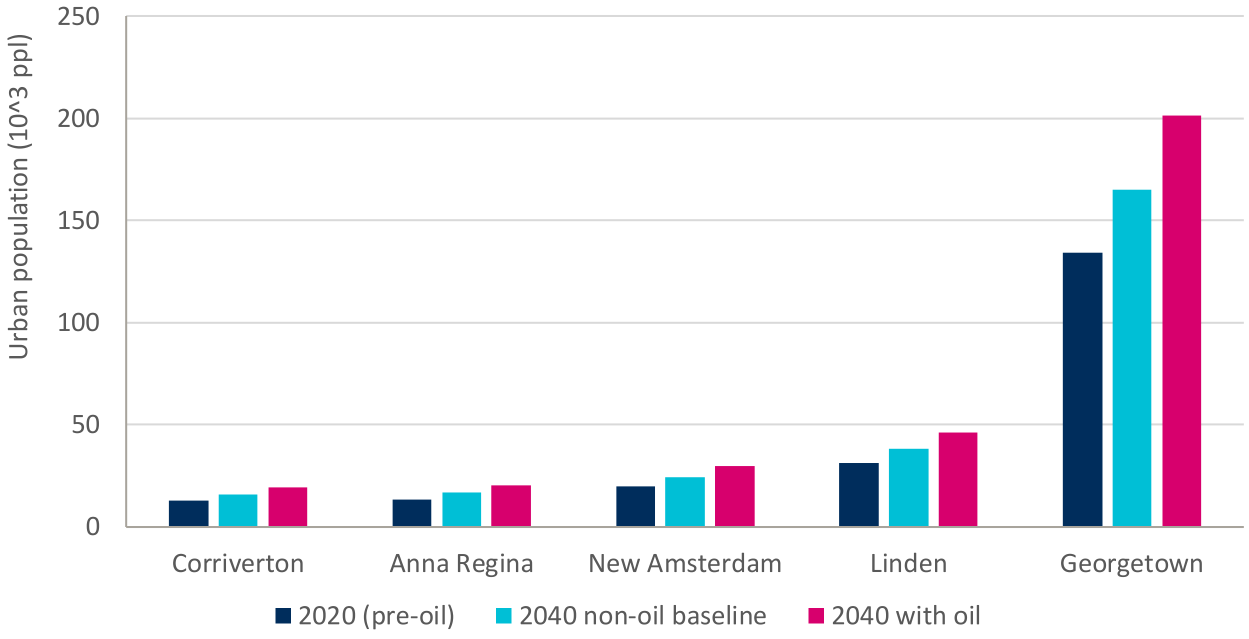
Many countries experience a similarly steep and marked increase in urbanisation following the discovery of oil. Among our case study countries, three experienced an increase in the urban share of over 20% in the 20 years following oil discovery. The highest, Oman, rose from 22% at the time of discovery to 57% 20 years later. In the highest growth scenario in Figure 5 above, Guyana's urban share rises to 45% in 2040 representing significant additional pressure on urban infrastructure.

Across the different sources of urban population growth, urbanisation is the most sensitive to oil production. Our projections account for increases in urban population through three channels. First, we consider population growth from people already residing in urban areas. Second, we consider people who move from rural areas to urban areas within Guyana. Third, we consider foreign workers who migrate to Guyana and settle in urban areas. The introduction of oil has a much more significant impact on the second channel than either the first or third.

Taking all of the above into account, the population of Georgetown is expected to rise by over 50% in the next 20 years. Our central projection sees a dramatic increase in the rate of population growth in Georgetown, with the current 2020 level of 133,000 reaching 201,000 by 2040, as demonstrated in Figure 6. Oil is expected to account for 36,000 of this increase. A similar rate of growth is expected across Guyana's other largest cities. Our projections assume that, due to the high cost of migration, all foreign workers choose to settle in Georgetown driven by its economic opportunities. In addition, we account for the likely size of the workforce that is based offshore without the need for housing or other urban services.[5] These two impacts counteract one another, leading to relatively little overall change in the population of Georgetown.

[5] Please see Section 3.2.2 for a full discussion of the projection methodology.

Figure 6 The population of each urban centre in Guyana is expected to rise by approximately 50%



Source: Vivid Economics

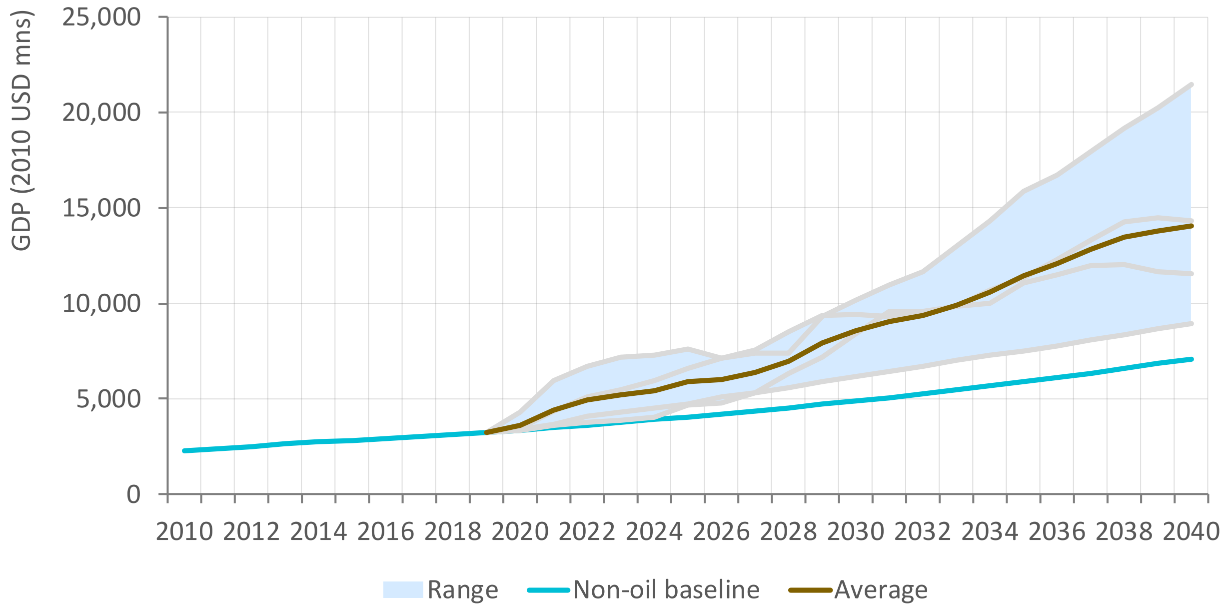
3.1.3 Economic activity

GDP is expected to rise dramatically from roughly USD 3.2 billion in 2019 to USD 14.1 billion in 2040, as demonstrated in Figure 7. This represents an increase of over 300% in the next 20 years. This is consistent with an average annual GDP growth rate of 7.3%, compared to just 3.8% in the non-oil baseline scenario. GDP growth is volatile following the discovery of oil. Across our case study countries, rates typically swung between 5% and 30% over the 20 years post-discovery. The highest rates of increase were seen in case study countries which developed downstream oil and gas industries – Kazakhstan and Oman. In the highest growth scenario, Guyana's GDP rises by roughly 560% to reach USD 21.4 billion in 2040.

While the oil and gas sector will account for a large share of this increase, it will also generate indirect economic growth in other sectors. This can happen in a number of different ways. First, the oil and gas sector itself could demand goods and services from the existing economy such as metals, machinery and fuel. Second, a significant portion of the money generated by the sale of oil and gas products could be spent on goods and services from the domestic economy. For example, new oil and gas workers are likely to spend some of their wages on accommodation and hospitality. Third, the development of an oil and gas sector may trigger innovation and the expansion of associated industries such as specialised legal and professional services.

GDP per capita follows a similar trend to GDP, increasing by roughly 300% between 2019 and 2040. Figure 8 shows this steep increase from USD 4,100 per capita in 2019 to USD 16,100 per capita in 2040. The fact that the pattern in Figure 8 is similar to that in Figure 7 indicates that GDP, as opposed to population, is the dominant driver of changes in GDP per capita. It is worth highlighting that the projections do not indicate the likely distribution of GDP per capita across the population and this does not imply an equal rise in all incomes.

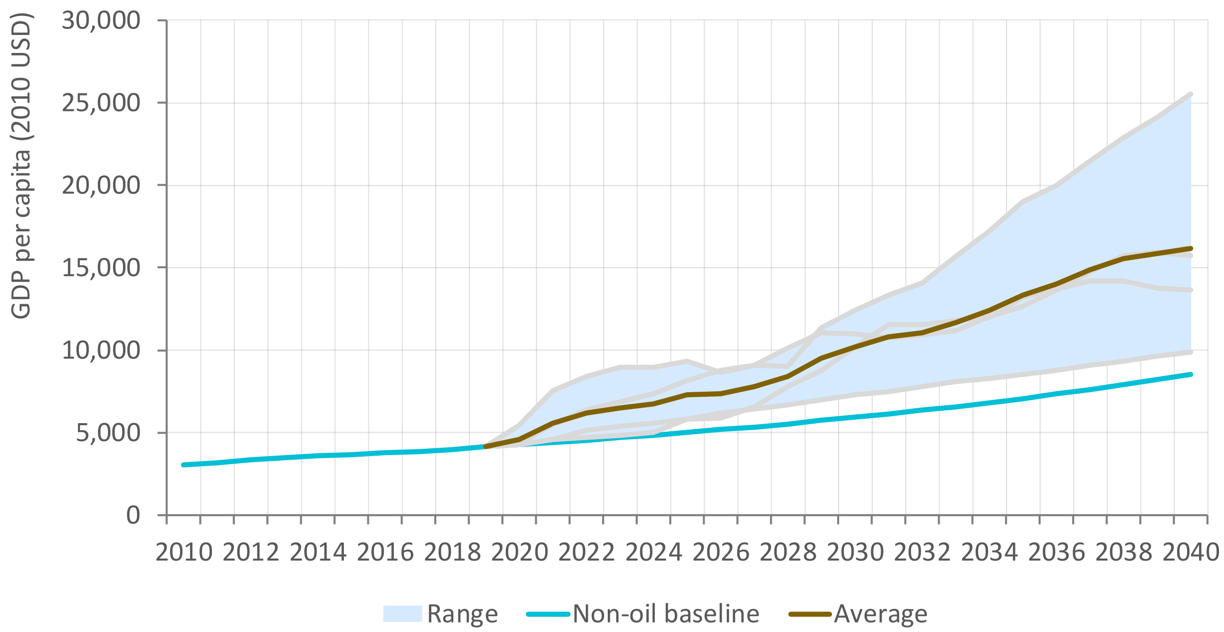
Figure 7 GDP increases by over 300% between 2019 and 2040



Note: Light grey lines represent results from each of the case study country scenarios described in Section 3.1.1 above. These inform both the range and average presented in the chart.

Source: Vivid Economics

Figure 8 GDP per capita follows a similar trend and reaches over USD 15,000 per capita by 2040



Note: Light grey lines represent results from each of the case study country scenarios described in Section 3.1.1 above. These inform both the range and average presented in the chart.

Source: Vivid Economics

3.2 BAU GHG Projections

Taking the Georgetown GHG inventory for 2016 and applying the anticipated GDP and population growth projections discussed above, the 'business as usual' GHG emissions by sector can be represented (see Figure 3). While this exercise is necessarily based on some high-level assumptions on the interlinkages between population/economic growth and GHG emissions, it is indicative of the course Georgetown might take in the absence of any interventions to reduce GHG emissions.

Over the time periods allocated, it is estimated that emissions will increase by 14% by 2030 and 55% by 2040.

The change in profile of the growth in emissions overall is largely driven by the growth of GDP and population anticipated in Georgetown as described above. GHG emissions through to 2026/2027 remain relatively stable in the buildings sectors (residential; commercial/institutional; and manufacturing industries) as Guyana's grid emission factor is projected to significantly reduce[6] in that timeframe before levelling off, at which point the 'demand growth' caused by population and GDP increases starts to drive the growth in emissions more directly.

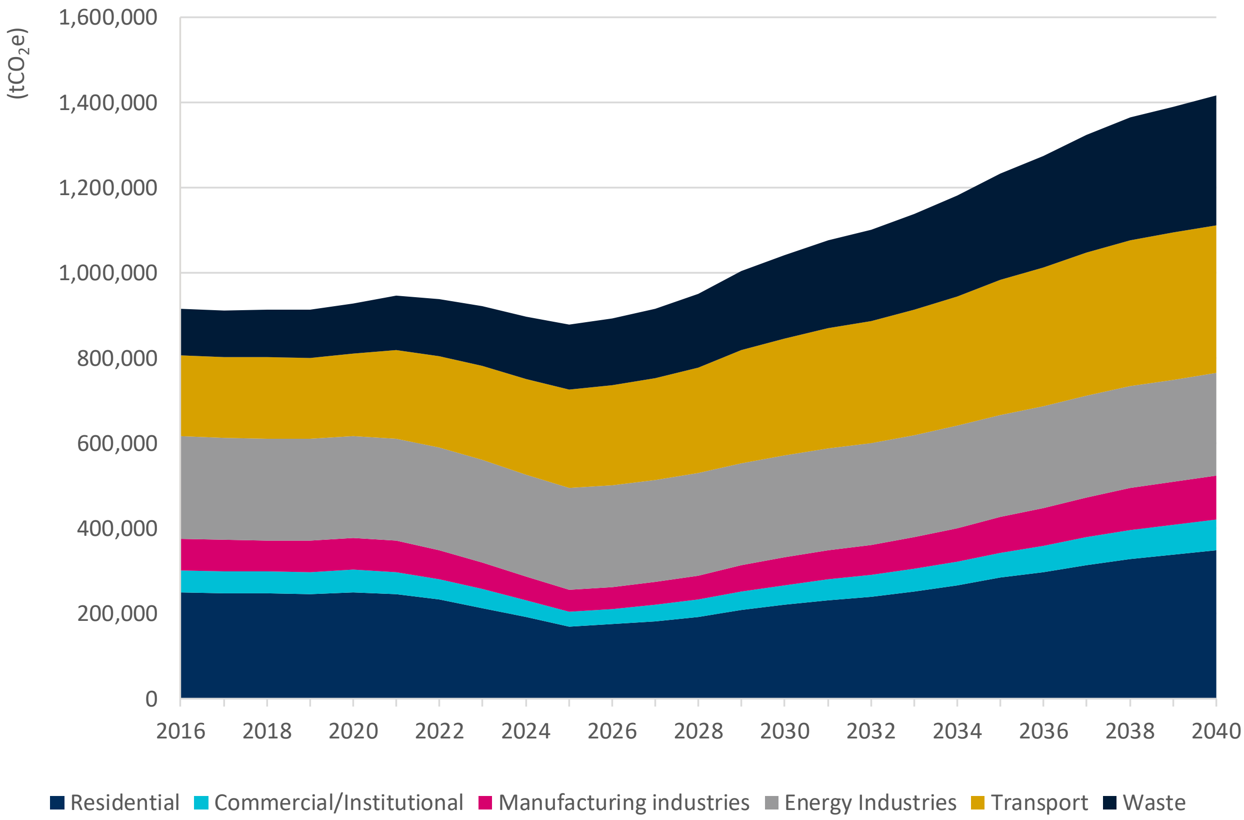
The 'Energy Industries' sector is depicting emissions arising from electricity generation at the Kingston Power Plant facility and therefore stays constant, based on the 'business-as-usual' assumption that it will continue to operate at the existing capacity and using existing technology.

The growth in demand for private vehicles is projected to grow significantly in the business-as-usual scenario, however the related growth in GHG emissions is mitigated by the baseline assumption that vehicle efficiencies will improve over the timeframe. In addition, GHG emissions from the aviation sector are predicted to increase in line with the GDP and population forecasts.

Projected growth in the emissions from waste are exclusively driven by the population and GDP growth projections.

[6] Projections of Guyana's grid emission factor were based on Alternative Scenario III from Guyana's Power Generation System Expansion Study (Brugman SAS, 2016), undertaken in conjunction with IDB and GEA. Please see Appendix D for a full description of these projections.

Figure 9 Estimated GHG emissions projections for Georgetown by sector from 2016 to 2040



Source: Aether; Vivid Economics

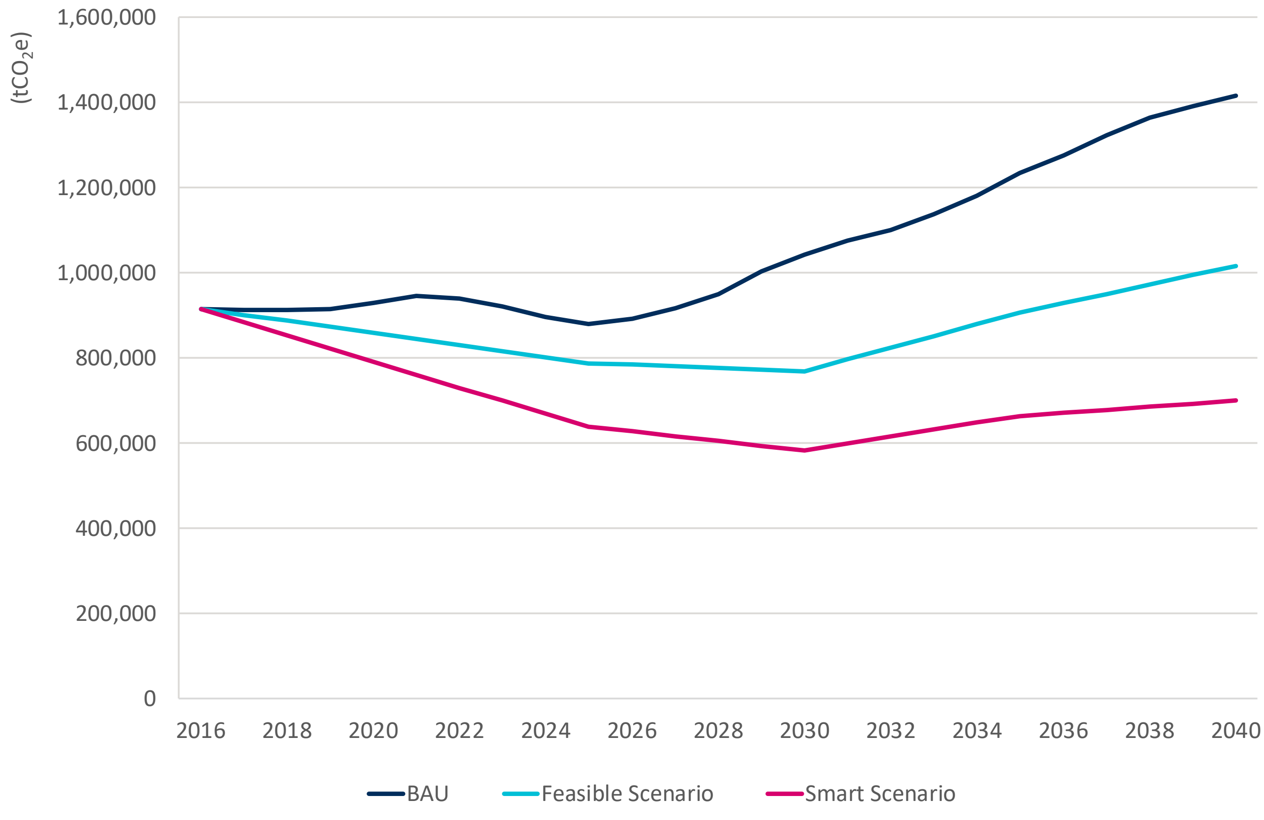
4 Feasible and Smart Scenarios

4.1 Emission savings

Through a thorough stakeholder consultation process with local ministries and organisations, a long-list of mitigation actions was identified for further assessment. This list was subsequently prioritised and filtered based on an analysis considering potential impact on reducing GHG emissions and the feasibility of implementation. A final list of priority actions is listed in Table 1, below. For each action a 'feasible' and 'smart' option was considered (described in Section 5) and the associated GHG emissions savings, costs and co-benefits assessed.

Figure 10 demonstrates that under the feasible and smart scenarios, GHG emissions in Georgetown could be up to 28% and 52% lower in 2040 respectively. Georgetown's emissions are expected to reach over 1.4 $MtCO_2e$ by 2040. The collective impact of all mitigation actions in 2040 could be as high as 0.4 $MtCO_2e$ in the feasible scenario and 0.7 $MtCO_2e$ in the smart scenario. From 2020 to 2040, this equates to a reduction in cumulative GHG emissions of 4.6 $MtCO_2e$ and 8.5 $MtCO_2e$ respectively.

Figure 10 GHG emissions in Business as Usual, Feasible and Smart Scenarios



Source: Aether; Vivid Economics

Table 1 List of prioritised actions and associated GHG emission savings in 2040 under the feasible and smart scenarios (tonnes of CO_2e).

Sector	#	Action	Scale of Feasible Action	Annual GHG Savings in 2040 (Feasible)	Scale of Smart Action	Annual GHG Savings in 2040 (Smart)
Transport	1	Optimization of Public Transport System	Introduce a fleet (430) of larger buses (and associated infrastructure) which operate on Compressed Natural Gas (CNG).	42,912	Introduce a fleet (430) of larger electric buses (and associated infrastructure).	65,147
	2	Converting Private Light Duty Vehicles	Transition to 50% of private vehicles fueled by CNG.	632	Transition to 50% of private vehicles to EVs.	7,194
	3	Converting the Public Vehicle Fleet	Convert 100% of the public fleet to CNG.	91	Convert 100% of the public fleet to EVs.	1,033
	4	Converting the Taxi Fleet	Convert 100% of the taxi fleet to CNG.	214	Convert 100% of the taxi fleet to EVs.	2,439
	5	Bicycle lanes	Install 28km of cycle lanes.	3,388	Install 28km of cycle 'highways' (i.e. dedicated roads) and 60km of cycle lanes.	14,036
Energy Generation	6	Rooftop Solar PV - Private Sector	Set a strategic target that PV panels could cover 5% (approx. 100MW) of Georgetown roof space by 2030 and 10% (approx. 200MW) by 2040.	105,871	Set a strategic target that PV panels could cover 10% (approx. 200MW) of Georgetown roof space by 2030 and 20% (400MW) by 2040.	211,741
	7	Rooftop Solar PV - Public Sector	Continue to install PV panels on government-owned buildings at the current rate of approximately 500kWp per annum through to 2040.	7,155	Accelerate the rate of installations from 500kWp per annum to 1MWp per annum through to 2040.	14,310
	8	Rooftop Solar Hot Water	Install SWH systems on 5% of Georgetown dwellings by 2030, 10% by 2040.	8,302	Install SWH systems on 10% of Georgetown dwellings by 2030, 20% by 2040.	16,605
	9	Kingston PP Fuel Switching	Convert both plants at Kingston to natural gas.	61,341	Convert both plants at Kingston to natural gas.	61,341

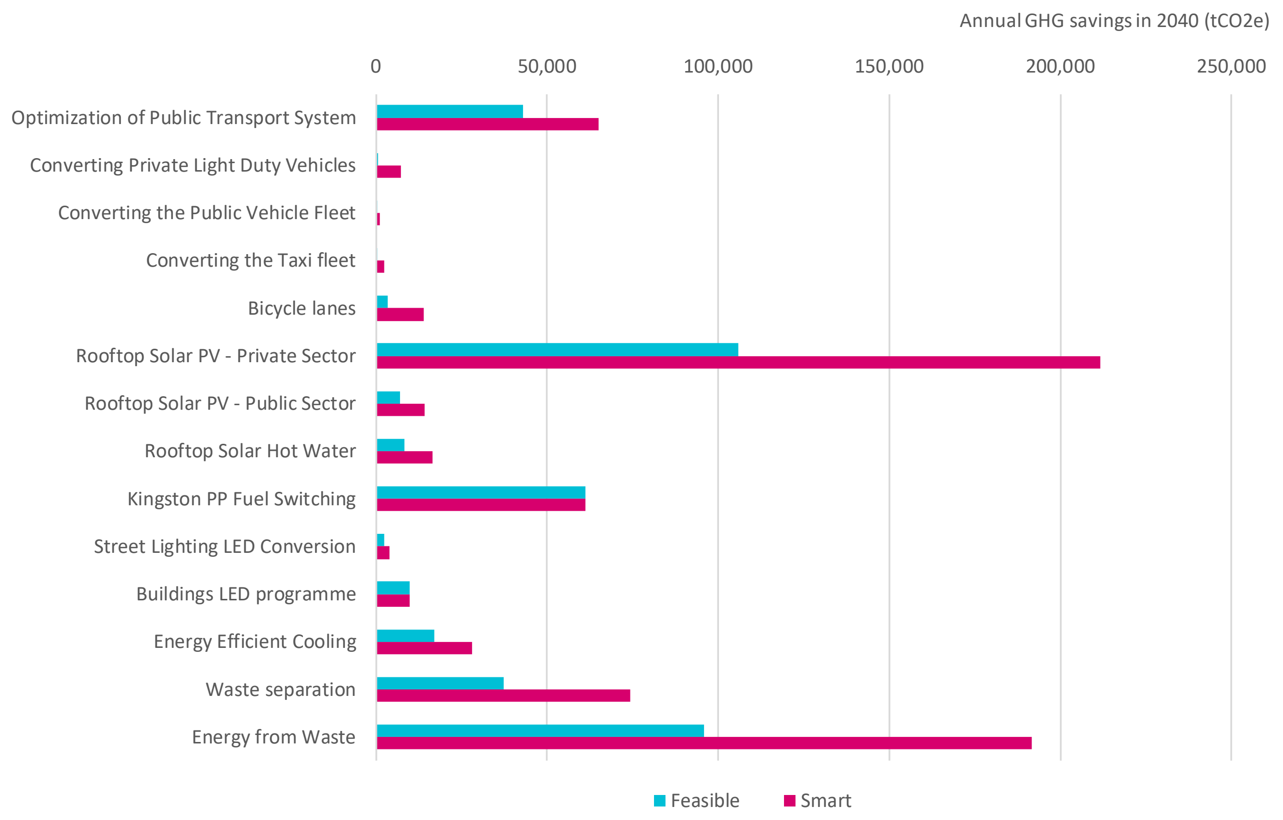
Energy Efficiency	10	Street Lighting LED Conversion	All street lights in Georgetown replaced by LEDs by 2030 and all future additional fixtures installed with LEDs.	2,390	All street lights replaced by LEDs by 2030 and all demand for future additional fixtures to be met with solar lights.	3,928
	11	Buildings LED programme	All domestic and commercial lighting to be transitioned to LED technologies by 2030.	9,783	All domestic and commercial lighting to be transitioned to LED technologies by 2030.	9,783
	12	Energy Efficient Cooling	Adopting a minimum SEER of 8 for the import and sale of cooling units.	17,058	Adopting a minimum SEER of 12 for the import and sale of cooling units.	27,993
Waste	13	Waste separation	50% of recyclable and biodegradable materials diverted from landfill.	37,217	100% of recyclable and biodegradable materials diverted from landfill.	74,434
	14	Energy from Waste	50% non-recyclable MSW incinerated with energy recovery.	95,847	100% non-recyclable MSW incinerated with energy recovery.	191,694
TOTAL SAVINGS				**392,201**		**701,678**

Note: Energy audits were also considered in the analysis but have been excluded from the totals in the table due to a lack of data concerning current energy efficiency levels and technology in use, making the estimation of likely implementation costs infeasible. This measure is estimated to contribute a saving of approximately 7 and 14 kilo tonnes of CO_2e in the feasible and smart scenarios respectively.

Source: Vivid Economics

The largest emission savings come from rooftop solar PV, energy from waste, fuel switching and optimising the public transport system. Figure 11 displays annual GHG savings in 2040 for each measure in both the feasible and smart scenarios (exact figures can be found in Appendix B). Collectively, the four top measures account for over 300 tCO_2e in 2040 in the feasible scenario and over 500 tCO_2e in the smart scenario, around three quarters of total mitigation. For several of these measures, savings in the smart scenario are close to the technical potential. For example, the optimisation of the public transport system involves translating the majority of public transport services to high capacity electric buses and the energy from waste plant incinerates 100% of non-recyclable waste in Georgetown.

Figure 11 Annual GHG savings in 2040 by measure and scenario



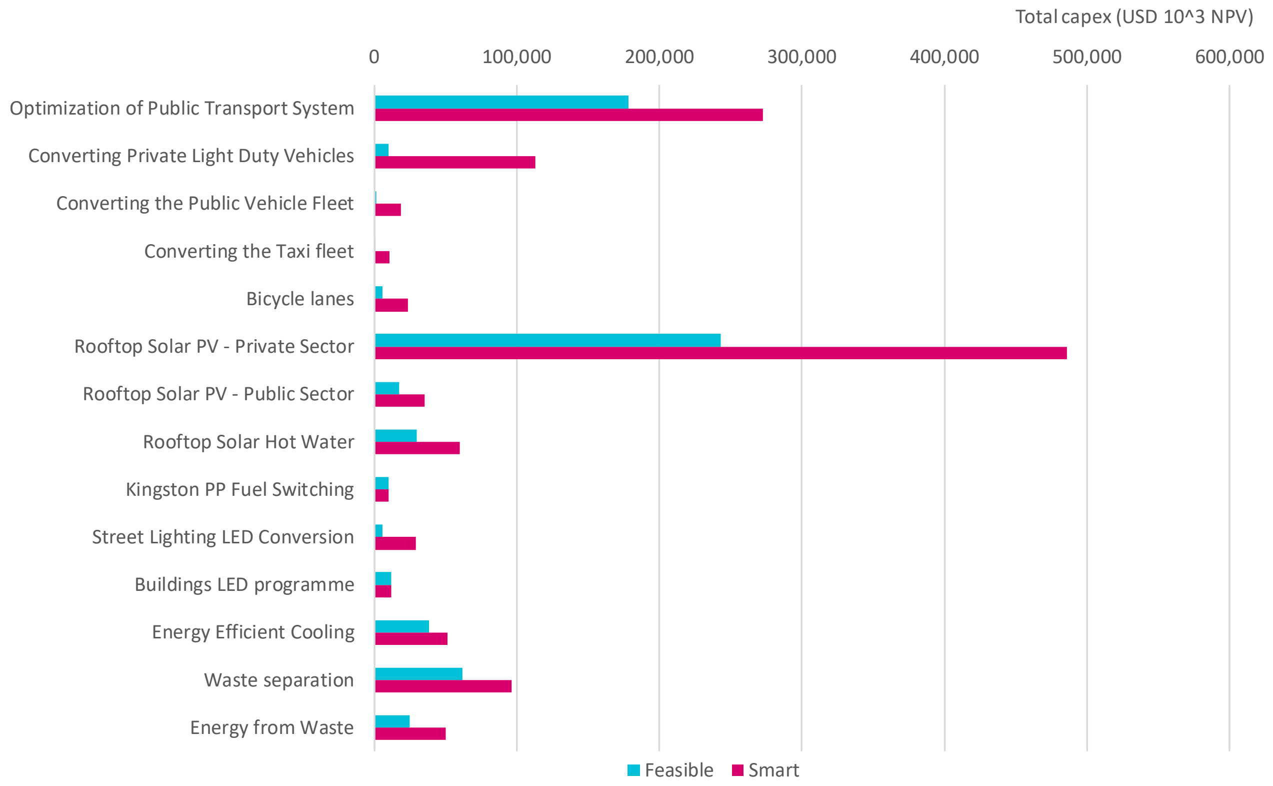
Note: Please see Appendix B for exact values.
Source: Aether; Vivid Economics

4.2 Capital and operating costs

Mirroring the emission savings, rooftop solar PV and optimising the public transport system have the highest up-front capital costs, as demonstrated in Figure 12 (exact figures, both aggregate and per unit, can be found in Appendix B). For the former, this reflects the cost of installing the panels and reaches over USD 240 million in present value terms in the smart scenario (to cover 20% of Georgetown's roof area). For the latter, this reflects the cost of purchasing new buses and is roughly USD 270 million in present value terms in the smart scenario (to purchase 430 electric buses). Converting the Kingston power plant to natural gas and building an energy from waste plant has comparatively lower capital outlays, considering the high emission mitigation potential indicated in Figure 11.

A large number of measures have relatively low capital costs, under USD 50 million in present value terms in the smart scenario. In some cases, this is due to the relatively small scale of implementation. For example, there are not many vehicles in the public vehicle or taxi fleets to convert to electric vehicles. In other cases, this is because measures mostly reflect changes in operational practices with little capital investment required, for example, switching to natural gas at the Kingston power plant. All measures consider the costs and savings associated with currently available technologies, in present value terms. [7]

Figure 12 Net present value (NPV) of total capital expenditure by measure and scenario



Note: Please see Appendix B for precise figures.
Source: Aether; Vivid Economics

Considering emission savings, capital expenditures and operational expenditures together, we can estimate the average unit cost of abating a tonne of carbon dioxide equivalent using each of the measures. Figure 13 and Figure 14 present marginal abatement cost curves (MACCs) for Georgetown under the feasible and smart scenarios respectively (exact figures can be found in Appendix B). A MACC plots the average unit cost of abatement[8] (on the y-axis) against the possible scale of that abatement (on the x-axis). As a result, a MACC tells you for each measure, (i) how expensive abatement is and (ii) how much you can abate. In some cases, measures can have a negative abatement cost. This occurs when the money saved each year in operational expenditure outweighs the initial capital investment. For example, in the case of optimising the public transport system, the money saved each year from running larger buses and using cheaper fuel eventually outweighs the initial cost of purchasing the new bus. For the measures below, we consider a 20-year timeframe from the first implementation of mitigation measures in 2020, out to 2040 in line with the Green State Development Strategy (GSDS) horizon.

[7] Future cash flows are adjusted assuming future annual inflation of 2% and a discount rate of 5%. We do not consider anticipated future reductions in technology costs or Guyana-specific import costs such as custom duties or taxes.
[8] Here, we have calculated the average unit cost of abatement over the 20-year timescale considered i.e. the average unit cost is equal to the cumulative total cost (both capital and operating expenditures) divided by the cumulative emission savings.

Figure 13 shows that, in the feasible scenario, Georgetown could reduce its BAU emissions by up to 15%, or by 217 ktCO_2e, in 2040 at negative cost. 8 out of the 14 measures considered have a net negative abatement cost over the 20-year timeframe in the feasible scenario. This means, by 2040, each of these measures will have generated financial savings that outweigh the initial capital or set-up costs. However, there may be additional barriers preventing their implementation such as lack of knowledge of technologies and processes, capital constraints, property rights and other legal barriers.

The lowest abatement costs are seen in rooftop solar hot water systems, LEDs in buildings and optimising the public transport system. Each of these measures have net abatement costs below USD -500/tCO_2e, though optimisation of the public transport system has by far the highest abatement potential at roughly 3% of BAU emissions or 43 ktCO_2e. In all cases, relatively small capital investments allow either substantial energy savings or the ability to switch to much lower cost fuels. Measures which reduce electricity consumption (either through efficiency or fuel switching) are likely to be effective low-cost mitigation options in Georgetown due to the high grid emission factor (increasing emission savings) and the high price of electricity (increasing financial savings). In addition, the construction of bicycle lanes, converting street lights to LED and installing rooftop solar PV across public sector buildings have net abatement costs between USD -500/tCO_2e and USD -50/tCO_2e. Together, all measures under USD -50/tCO_2e generate savings of 5% of BAU emissions or 74 ktCO_2e.

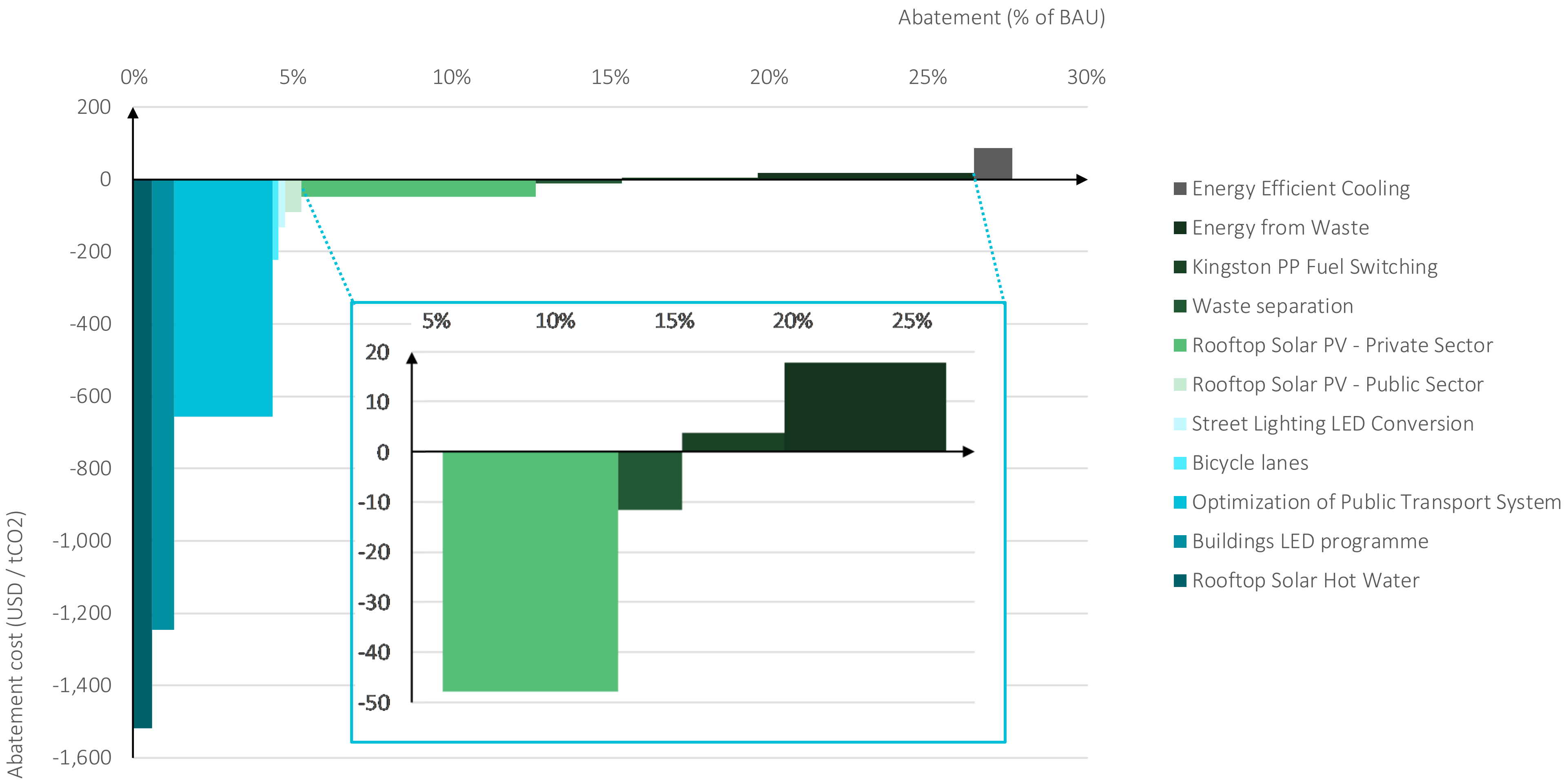
The highest cost options considered are converting the vehicle and taxi fleet to CNG and energy efficient cooling. Conversions of the public, private and taxi fleet all have relatively little abatement potential (less than 0.1% of BAU emissions each) and are hence excluded from Figure 13. [9] Energy efficient cooling could reduce 1.2% of BAU emissions or 17 ktCO_2e but at a high abatement cost of USD 85/tCO_2e. The high cost of these measures mean they are unlikely to be implemented by the private sector and do not represent a cost-effective investment for the public sector.

Figure 13 highlights the four remaining measures that allow combined saving of about 21% of BAU emissions or 300 ktCO_2e in 2040. All have negative, or positive but low, net abatement costs and account for a large portion of total abatement potential. Rooftop solar PV and the energy from waste plant are the two largest measures with abatement of 7.5% and 6.8% of BAU emissions respectively. Fuel switching at the Kingston power plant and a waste separation facility have slightly less but still large abatement at 4.3% and 2.6% respectively.

Public sector actors can play an important role in encouraging private sector implementation of those mitigation measures that have a positive but reasonably low net abatement cost. A large range of policy tools exist to support this. Some provide direct economic incentives such as feed-in tariffs, carbon prices and concessional finance schemes. In many cases, reducing existing incentives for ‘traditional’ measures can make mitigation measures more economically attractive. Other policies provide non-monetary support such as technical assistance, matchmaking with potential investors and legal advice.

[9] Their average abatement costs all exceed USD 700/tCO_2e, even excluding the cost of associated CNG fuelling infrastructure.

Figure 13 Marginal abatement cost curve (MACC) for the feasible scenario in 2040



Note: Abatement costs are presented in net present value terms. 2040 BAU emissions are equal to 1.42 $MtCO_2e$. Measures with abatement lower than 0.1% of BAU emissions (1.42 $ktCO_2e$) are excluded from the chart.

Source: Vivid Economics

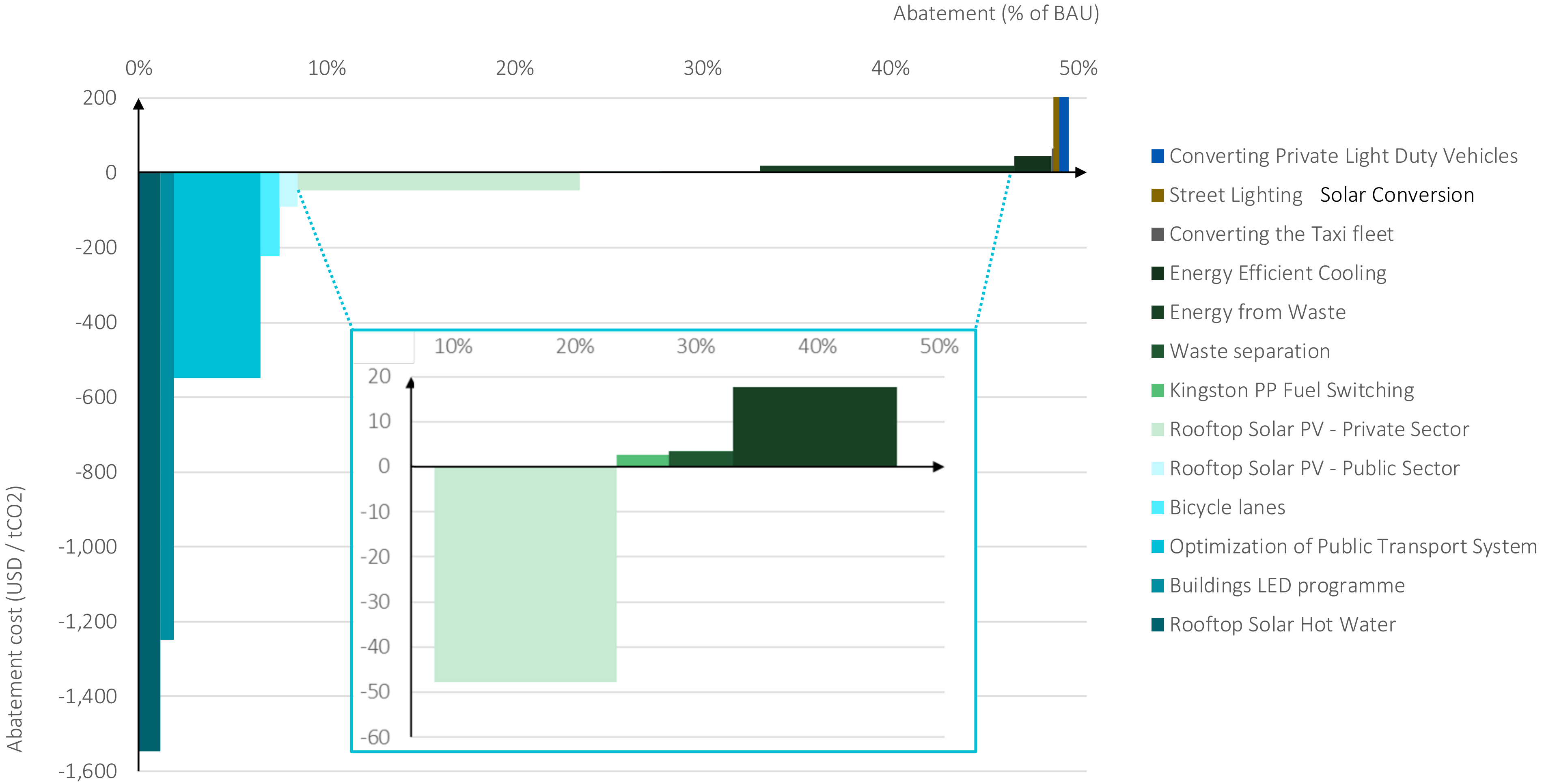
Figure 14 shows that, in the smart scenario, Georgetown could reduce its BAU emissions by up to 23%, or by 332 ktCO_2e, in 2040 at negative cost. 6 out of the 14 measures considered have a net negative abatement cost over the 20-year timeframe in the smart scenario. Typically, measures have higher unit abatement costs but also higher abatement potential in the smart scenario relative to the feasible scenario.

As in the feasible scenario, the lowest abatement costs are seen in rooftop solar hot water systems, LEDs in buildings and optimising the public transport system. All still have abatement costs below USD -500/tCO2e though generate more abatement under the smart scenario: 1.2%, 0.7% and 4.6% of BAU emissions respectively. Bicycle lanes and installing rooftop solar PV across public sector buildings again have net abatement costs between USD -500/tCO_2e and USD -50/tCO_2e. Together, all measures under USD -50/tCO_2e generate savings of 8.5% of BAU emissions or 120 ktCO_2e.

The highest cost options considered are converting the vehicle and taxi fleet to electric vehicles and converting incandescent street lamps to solar and energy efficient cooling. Conversions of the public, private and taxi fleet have more abatement potential (<0.1%, 0.5% and 0.2% of BAU emissions respectively) but are still some of the least important measures. Solar street lamps offers a further 0.3% emission reductions but at the high cost of USD 315/tCO_2e. Finally, energy efficient cooling could abate 2% of BAU emissions at a moderately high cost of USD 45/tCO2e.

Figure 14 highlights the four remaining measures that allow combined saving of about 38% of BAU emissions or 540 ktCO_2e in 2040. All have negative or positive but low net abatement costs and account for a large portion of total abatement potential. Rooftop solar PV and the energy from waste plant again account for the most abatement with 15% and 13.5% of BAU emissions respectively. Fuel switching at the Kingston power plant and a waste separation facility have slightly less but still large abatement at 4.3% and 5.3% respectively.

Figure 14   Marginal abatement cost curve (MACC) for the smart scenario in 2040



Note: Abatement costs are presented in net present value terms. 2040 BAU emissions are equal to 1.42 $MtCO_2e$. Measures with abatement lower than 0.1% of BAU emissions (1.42 $ktCO_2e$) are excluded from the chart. Street light conversion and conversion of the public vehicle fleet have costs exceeding USD 200/tCO_2e.

Source: Vivid Economics

5 GHG Mitigation Options

5.1 Transport

Mitigation actions suggested for the transport sector not only reduce transport GHG emissions but also tackle some of Georgetown's most pressing issues:

There was consensus amongst all stakeholders interviewed that mobility was one of the key issues facing Georgetown today. The number of vehicles is increasing, and this is leading to congestion in the City at peak times. The number of road traffic accidents is also a cause for concern; in 2017, there were 118 deaths due to road traffic accidents in the Country as a whole, which equates to 15.88 people per 100,000.

According to the Pan-American Health Organization (PAHO) obesity rates among adults in the country climbed from 35 percent in 2006 to 44 percent in 2010, and 55 per cent in 2016 [10]. According to the PAHO study, being overweight is one of the underlying causes of death in Guyana and two out of every three deaths in the country are attributed to non-communicable diseases — heart disease, hypertension, diabetes and strokes — all of which are related to obesity. It is therefore important that residents are encouraged to exercise, and this includes encouraging people to use non-motorised transport such as walking and cycling to go about tir daily lives. At the present time, there are few designated walking and cycling routes in the city.

5.1.1 Public Transport System Optimisation

In 2016, a Sustainable Urban Transport Study (SUTS) for Georgetown was commissioned, aimed at improving mobility in and around Georgetown. According to the study, the public transport fleet in Georgetown is composed of 95% minibuses and 5% larger motor buses, which are owned, operated and maintained by the private sector. Roughly 6,054 vehicles for 2016 were licensed as public transport vehicles in 2016, in which 953 vehicles are licensed in routes that travel inside Georgetown and 5,101 cover routes that leave Georgetown.

In terms of public transportation, the key recommendation of the SUTS is to convert the current system into one that incorporates many more large buses, thereby reducing:

- number of vehicles to maintain/ regulate;
- associated fuel consumption and fuel costs;
- congestion on the roads;
- emissions of air pollutants; and,
- GHG emissions.

In addition, this measure would vastly improve mobility in the city, providing a regulated and dependable service for citizens. It includes the construction of a new bus terminal on Water Street.

With the implementation of this new public transport system, there is a significant opportunity to invest in buses and infrastructure that will offer improved cost efficiency during operation and provide significant reductions in GHG and air pollutant emissions over their lifespans (compared to a traditional diesel-powered bus). The SUTS estimates that approximately 430 new buses would meet the demand of the new and existing routes needed.

The feasible option for this action uses CNG as the fuel source which could take advantage of the newly discovered natural gas resources which will be landed in Guyana. Significant infrastructural and logistical

[10] https://www.kaieteurnewsonline.com/2018/02/07/obesity-among-children/

(fuel delivery) processes would need to be put in place, but it could result in a significant decrease in GHG emissions and air pollutants.

The smart option utilises electric buses for the new bus fleet. This option could completely remove dependence on fossil fuels for buses in Georgetown and would result in zero tailpipe emissions. For this to be beneficial from an operation cost and GHG emissions perspective, it would need to be paired with the decarbonisation of the electricity grid and likely a decrease in the unit cost of electricity.

Box 1 **CASE STUDY: BOGOTA**

The city began testing electric and hybrid buses in 2014, as part of the Latin American Hybrid Electric Bus Test Program (HEBTP). Bogotá's goal is to replace thousands of buses with low-emissions vehicles is one of the most ambitious electric vehicle programs in the world. New electric buses which are being deployed will curb 135 tons of CO_2 emissions every year and can cover over 400 kilometres on a single charge with a recharging time of three hours.

Source: https://www.siemens.com/press/pool/de/events/2014/infrastructure-cities/2014-06-CCLA/bogota-climate-close-up.pdf

5.1.2 Conversion of Private Fleet

Ultimately, following the potential adoption of pilot projects in the public and/or taxi fleets (described below), the goal is for widescale acceptance and purchasing of low emission vehicles across Georgetown (and Guyana). This initiative has already started to take shape with the government's promotion and establishment of duty relief for hybrid and electric vehicles. The focus of the government is currently on promoting all-electric vehicles as oppose to hybrid, with the aim of charging the vehicles with solar energy where possible.

The feasible option for this action considers transitioning to CNG-fuelled vehicles. As with the public transport option, installing the CNG fuelling infrastructure would require significant capital expenditure and logistical planning, however implementing this policy focused on the private fleet could make the public and taxi fleet pilots more economically viable.

The smart option involves transitioning to electric vehicles. This approach has already been initiated by the Guyanese government, but it is likely that financial incentives for purchasing EVs would have to be improved and charging points installed to drive uptake. Unlike the public and taxi fleet pilots, less public EV charging points per EV would be required as charging largely takes place at home with private vehicles, though some incentive for installing home-based charging equipment may be needed. Free parking for electric vehicles and free charging in certain public locations would also help establish a market for EVs.

Guyana's electricity grid is currently relatively carbon intensive and so will need to be decarbonised in order for electric vehicles to reach their maximum potential in terms of reducing GHG emissions. However, with other measures recommended in this study (see Section 4.2) and Guyana's Nationally Determined Contribution (NDC) aiming at significantly growing the level of renewable energy over the coming years[11].

The large-scale transition to low carbon (electric vehicles) is highly likely in the long-term as global car manufacturers scale up their production to respond to national government policy or by improving cost-benefit of these new technologies. Georgetown (and Guyana) has the opportunity to accelerate this transition, which can reap huge environmental and economic benefits, especially if the electrical grid can be decarbonised and the unit cost of energy reduced. Guyana's abundant solar energy potential could power clean and cheap mobility in the city.

Box 2 **CASE STUDY: BARBADOS**

Barbados is already the third highest user of electric vehicles in the world in terms of EVs per capita. Following the government pilot programme whereby eight electric vehicles were purchased, a fledging EV sector has established itself which has yielded over 390 privately owned EVs. This has also resulted in new jobs in the sector as organisations have been created to import and maintain EVs.

Source: https://www.siemens.com/press/pool/de/events/2014/infrastructure-cities/2014-06-CCLA/bogota-climate-close-up.pdf

5.1.3 Conversion of Public Vehicle Fleet

Internationally, car manufacturers are transitioning towards producing lower carbon vehicles. Hybrid electric vehicles (HEVs – which combine a fuel engine with electric elements) and electric vehicles (EVs) are expected to outsell conventional combustion cars by 2030[12]. In the interim, some countries are providing infrastructure and incentives for vehicles which can be converted to and run on CNG, which can also have a suite of economic and environmental benefits in the short-term.

To drive the adoption of these technologies in the private vehicle fleet, cities and countries often focus on implementing pilot initiatives with the public vehicle fleet. This can assist with providing the necessary infrastructure (i.e. CNG fuelling stations or EV charging points) and testing/demonstrating the vehicles in the local context. Public authorities can subsequently use the earned benefits of the pilot and policy leavers to promote wider uptake in the private market.

In Georgetown, between the national government ministries and the city council, the public fleet comprises a significant proportion of the fleet and could provide a useful demonstration of the new technologies, while making a significant impact in reducing emissions. It is estimated there is approximately 300 vehicles in the public vehicle fleet in Georgetown currently.

The feasible option for this action is to convert public vehicles to CNG. While this is a low-cost option in terms of the conversion of the fleet (the cost of converting a diesel or petrol vehicle to CNG is marginal), the relative infrastructure and fuel delivery costs may be significant. As Georgetown does not have an existing natural gas grid, CNG would need to be delivered to dedicated refuelling stations around the city. While this

[11] See section 3.1 on the future Guyana electric grid emission factor projection
[12] https://www.jpmorgan.com/global/research/electric-vehicles

could be managed at one or two stations in the city, the cost and logistical organisation of fuel delivery would be significant. The adoption of CNG in the public fleet would likely need to be matched with a broader policy and incentives for conversion to CNG of the private fleet to create the necessary scale.

The smart option for this action considers transitioning public vehicles to EVs. This would result in somewhere between 5 and 10% of vehicles in Georgetown being EVs and therefore offer a significant pilot exercise for the city, while reducing the operating costs of public authorities and reducing GHG and air pollution emissions.

The Guyana Energy Agency (GEA) and Guyana Power and Light (GPL) are already in discussions to introduce EVs into the public fleet by 2019 with the introduction of the first EV charging point at its premises in Georgetown. Pending its introduction, the amount of EVs in the public fleet could be scaled up quickly.

Box 3 **CASE STUDY: BARBADOS**

In 2017, the government of Barbados took the first steps in promoting EVs with the launch of the government pilot project (funded by IADB and the European Commission). The pilot project initially involved eight EVs shared between government departments and powered by solar photovoltaic systems. The pilot has been a success and the government is currently converting more vehicles to electric. The pilot project has encouraged public uptake of electric vehicles and Barbados is currently the third highest user of EVs in the world per capita.

Source: https://www.smart-energy.com/news/barbados-electric-vehicle-pilot-project/

5.1.4 Conversion of Taxi Fleet

The transition to adopting EVs across Georgetown and Guyana will require gradual improvement of EV infrastructure. Taxis have high mileage and are frequently idle, therefore the economic benefit of converting the taxi fleet to EVs is proportionally higher than with private use vehicles. Paired with the right incentives, this can also be a valuable proposition to the taxi industry as operating costs (maintenance and fuel) can be significantly reduced. Many cities are now focusing on transitioning taxi fleets to EV or hybrid technologies to reduce GHG and air pollutant emissions using a regulatory approach and by providing the financial incentives and infrastructure to support the transition.

There were approximately 170 taxis registered in Georgetown in 2017, all of which could be targeted for replacement with alternative technologies when they reach the end of their useful lives and new vehicles are being purchased and registered.

The feasible option is to convert taxis to CNG. As with the equivalent measure for the public fleet, this is a low-cost option in terms of the conversion, but the relative infrastructure and fuel delivery costs may be significant. As Georgetown does not have an existing natural gas grid, CNG would need to be delivered by tanker to dedicated refuelling stations around the city. While this could be managed at one or two stations in the city, the cost and logistical organisation of fuel delivery would be significant. The adoption of CNG in the taxi fleet would likely need to be matched with a broader policy and incentives for conversion to CNG of the private fleet to create the necessary economy of scale.

The smart option is to convert the taxi fleet to EVs. The associated charging infrastructure would be relatively cheap compared with CNG, as charging stations can connect easily into the electrical grid system. The suggested ratio of charging points per vehicle is 1:5 so approximately 40 charging points would be required for the taxi fleet, though these could be clustered at locations throughout the city to manage installation costs.

Box 4 **CASE STUDY: BOGOTA**

In 2013, Bogota launched a pilot project for electric taxis, creating a fleet of 50 EVs and 5 charging points to service the city. The pilot project was part of a broader policy framework to accelerate the uptake of EVs which included tax incentives to improve the financial benefit of EV ownership.

Source: https://www.siemens.com/press/pool/de/events/2014/infrastructure-cities/2014-06-CCLA/bogota-climate-close-up.pdf

5.1.5 Bicycle Lanes

There is currently very little travel by bicycle in Georgetown, considered partly as a result of limited infrastructure and some dangerous conditions on the road for cycling. The SUTS report states that "*The lack of infrastructure for pedestrians and cyclists runs counter to the principles of a sustainable and inclusive transport system.*"

Establishing a safe system of dedicated cycle lanes in Georgetown can drive the mode shift from private vehicles to bicycles. The city's flat topography is well-suited to bicycle travel and a large proportion of the city's inhabitants live within a cyclable distance of the city centre. The Ministry of Public Infrastructure have created policy mandating all new road designs to have cycling lanes.

Roads or access ways could be converted for exclusive use of pedestrians and cyclists and absent of any vehicular traffic, or at minimum cycle lanes could be cordoned off from vehicular traffic to protect the safety of its users. Main 'arteries' of the bike system could be complemented with dedicated bike routes and walkways for access from nearby commercial hubs where needed.

The feasible option assesses developing two cycle lanes, one running East-West from UoG to Stabroek Market (6.5km) and one running North-South from Kingston to the Demerara Harbour Bridge (7.5km) by 2030. This would be a pilot project to determine the attractiveness of cycling as a mode of transport to the citizens of Georgetown. Once the concept has been proven successful, the amount (kms) of cycle lanes could be doubled by 2040.

The smart option considers building wide, dedicated active travel 'highways' on main East-West and North-South avenues (14km) with supporting cycle lanes (for example, 3 East-West lanes and 3 North-South lanes totalling 30km) to create a 'grid system'. Depending on use and capacity, the amount (kms) of cycle lanes could be doubled by 2040.

Box 5 **CASE STUDY: BOGOTA**

Bogota has been rapidly scaling up its cycle infrastructure since 2015 and is now seeing subsequent growth in ridership. Overall, trips by bicycle have nearly trebled since 2005 as the city tries to alleviate its congestion and air quality issues. One of the reasons for this increase has been the expansion of the bike lane network of over 80km in the past two years.

Source: https://www.c40.org/case_studies/upgrade-of-the-cycle-network-in-bogota-dramatically-increases-bike-trips

5.1.6 Co-benefits of Transport Actions

Electric vehicles

Transport is a major source of air quality emissions around the world. The use of electric vehicles can therefore offer a potential for substantial local air quality benefits as there are no emissions at point of use. There will still be emissions of particulate matter due to brake and tyre wear, however these are not significant enough to outweigh the overall wider benefits of the switch.

There could also be indirect economic benefits for other sectors, such as renewable energy. One challenge of renewable energy is storage due to the intermittent nature of some sources. Electric vehicles could fill this role by acting as both transport and energy storage. There is potential for this to stimulate the growth and development of wind technology in conjunction with electric vehicles.

Fuel prices can be volatile and vulnerable to shocks whilst electric vehicle and battery costs are declining as demand increases. Fuel prices are a contentious issue in Guyana, with minibus operators and owners protesting the high fuel prices during summer 2018 (Guyana Times, 2018). This creates a major driver for investment in low emission vehicles.

Noise pollution from transport vehicles can have a broad range of negative health impacts including disturbed sleep patterns, reduced cognitive function, raised blood pressure, stress, and cardiovascular disease. Electric and hybrid vehicles offer the potential for noise reduction especially in urban areas. This reflects that at the lower vehicle speeds typically associated with urban areas, the propulsion noise from electric vehicles is lower. It is important to note that tyre noise and the vehicle itself dominates the noise profile at over 25 mph and therefore in rural areas and motorways the benefits would be lower. Due to the quiet nature of electric vehicles, there may also be a heightened risk to walkers and cyclists with an increased chance of accidents as active travellers rely on their hearing to identify dangers. This conflict can be minimised through planning and prioritisation of walkers and cyclists and the fitting of noise devices. Infrastructure developments to make walking and cycling routes safer, such as good lighting and provision of crossings can help to reduce the chance of accidents.

There is a need however for further research on the potential adverse side effects on land and water from mining and manufacturing processes required for electric vehicle materials.

Transition to CNG vehicles

Emissions of particulate matter and nitrogen oxides (NOx) from CNG are significantly lower than from diesel or petrol vehicles, in part due to a more complete combustion cycle. Potential air quality improvements from the transition to CNG vehicles will depend though on the vehicle types converted or replaced. However, CNG fuel has the potential for increased emissions of carbon monoxide and ozone precursors.

CNG can offer financial benefits to drivers reflecting that it is a lower cost fuel on a per kilometre basis than diesel, gasoline and electric vehicles. This could however lead to a rebound effect of increased air pollution and GHG emissions where because the cost to the user per vehicle kilometre travelled is reduced, transport activity may increase.

Conversion to CNG vehicles offers potential GHG emission savings. However, investing in CNG fuelling infrastructure commits Guyana to long-term use of fossil fuels in transport.

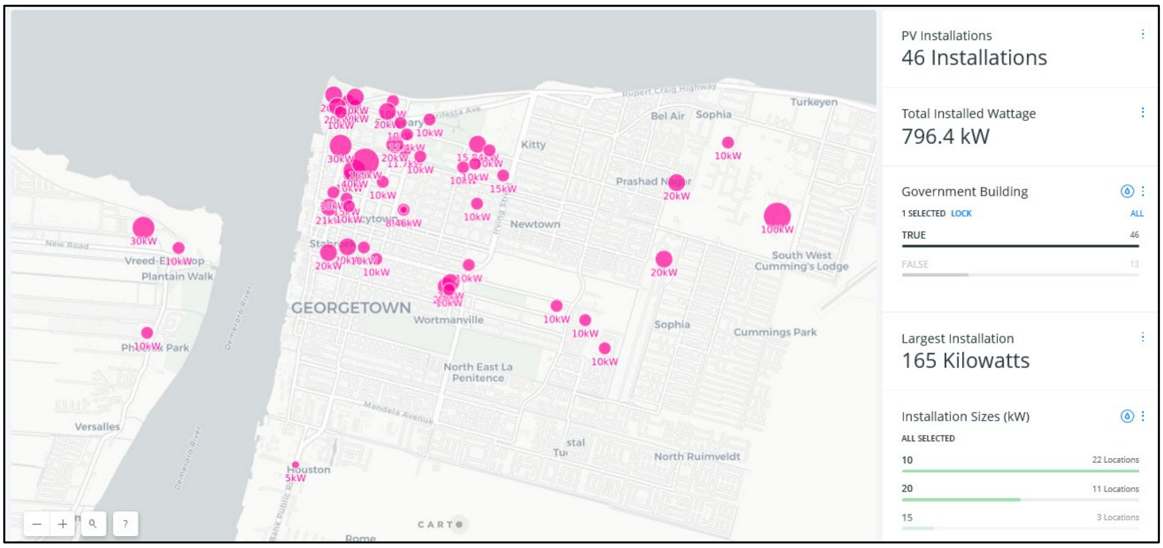
5.2 Energy Generation

Generally, the economic argument for solar energy is very strong in Caribbean nations, both photovoltaic (PV) and solar water heating (SWH) technologies. High fuel import costs coupled with the high levels of insolation and annual hours of sunlight create the perfect storm for deployment of solar technologies. This benefit is further compounded by offering the potential for enhanced energy independence and resilience. ~~This~~ is certainly the case in Guyana where the high unit cost of electricity results in very short payback times for investments in PV, though this may come down in the future with the development of the oil and gas industry. [13]

5.2.1 Rooftop Solar PV - Public Buildings

Guyana Power and Light (GPL) are already leading an ambitious programme to install PV on government-owned buildings in Georgetown (and across Guyana). Over the last few years roughly 500kW$_p$ per annum of capacity has been installed. This trend is set to continue with GPL targeting many more installations and sites soon. GPL are also planning the development of 5 solar farms (mostly outside the city boundary), with a capacity of at least 10MW$_p$ each.

Figure 15 PV Installations in Georgetown



Source: https://gplgis.carto.com/builder/18240d39-7798-4dfd-b7cd-45d7e63b21cf/embed

[13] If Guyana either develops downstream refining capacity or a gas-fired power plant, it is likely that the cost of electricity will significant fall in the future. However, it is not currently possible to estimate this due to the uncertainty surrounding both the Government of Guyana's policy position on the development of the oil and gas sector and the pricing strategy of Guyana Power and Light (GPL).

Box 6 **CASE STUDY: ST. LUCIA**

Determined to shift away from fossil fuels, the island nation of Saint Lucia is turning to solar energy for electricity generation, with a contract signed between electric utility St. Lucia Electricity Services Limited (LUCELEC) and Spanish engineering group Grupotec for a 3 MW solar project, will power approximately 1.3% of the country's electricity needs.

Source: https://www.pv-magazine.com/2017/06/22/saint-lucia-to-get-first-utility-scale-solar-plant/; http://newenergyevents.com/caribbean-renewable-energy-five-projects-were-watching-in-2018/

5.2.2 Rooftop Solar PV – Private Buildings

To maximise the PV potential in Georgetown and to make a significant contribution to decarbonising the electricity grid (and likely offer significant savings on unit energy costs), utilising the 'real estate' of domestic, commercial and industrial rooftops in the city can be a cost-effective means of building capacity.

Based on estimates taken from satellite imagery, there is approximately 17.5 km^2 of available roof space in Georgetown which could be available for installation of PV panels and generating clean electricity. Currently, of the circa 1,500 kW_p of installed PV in Georgetown, only about 500 kW_p is from installations on non-government buildings. A rapid scale-up of PV electricity generation will be necessary to contribute to the country's Low-Carbon Development Strategy, which aims at sourcing all the country's energy demand from renewables by 2025.

In order to encourage the residential and private sectors to engage and invest in solar generation, a suite of incentives will need to be developed to offset the capital costs involved in installation of the panels. GPL is planning to establish a feed-in-tariff pilot, which will be key to creating the necessary financial incentive.

Box 7 **CASE STUDY: DOMINICAN REPUBLIC**

The Dominican Republic are establishing a policy landscape to incentivise the installation of PV by its citizens and businesses. There are a broad range of tax incentives, including a 100% exemption for renewable energy technologies from import taxes, a 10-year tax exemption on income generated from the sale of renewable energy power and equipment, a reduction of taxes on external financing, and a 75% tax credit for self-producers (defined as systems smaller than 1.5 MW). Furthermore, there are low interest loans for community projects, which cover up to 75% of the cost of equipment for small-scale installations (< 500 kW). Finally, a feed-in tariff (FiT) for grid-connected renewable energy installations is available.

Source: https://www.nrel.gov/docs/fy15osti/64125.pdf

5.2.3 Rooftop Solar Hot Water

Similar to PV, generating hot water using solar energy is a particularly attractive option in tropical countries. The fact that there are typically no natural gas networks means that there is a reliance on bottled LPG (typically) to provide hot water. When this is combined with the high costs of importing fuels, there is a premium paid on water heating. Although Guyana's discovery of its own natural gas resources may mitigate this issue, the cost-benefit of SWHs still outweighs that of fuel heating systems.

There is a drive from the Guyanese government and GPL to encourage installation of SWH systems, with GPL implementing a program to facilitate installation. If these efforts can ultimately work to establish a local industry to supply and install the systems, it will likely trigger market mechanisms and result in significant uptake.

Box 8 **CASE STUDY: BARBADOS**

Barbados has one of the highest per capita SHW usage in the world. The Government of Barbados provided incentives and low interest loans to seed a SWH industry, since which the industry has proliferated independently. The financial payback for SHW systems in the Caribbean is very short meaning there is a natural demand for systems once the supply side is established. SWHs designed in Barbados are sold throughout the region, and Barbados is recognized as a leader in the SWH field.

Source: https://www.energy.gov/sites/prod/files/2015/03/f20/phase3-barbados.pdf

5.2.4 Kingston Power Plant Fuel Switching

Kingston Power Station, located in the heart of Georgetown, has two plants commissioned in 1997 and 2009 respectively. The plants have a combined capacity of 58 MW and annual electricity production in the region of 380 GWh. The plants combust fuel oil and gas oil to generate electricity leading to significant GHG emissions and air pollutants in the city.

Figure 16 Kingston Power Plant (#2)

Source: https://ppdi.gy/index.php/pt/power-plants/kingston-2

With the discovery of Guyana's new oil and gas resources, Kingston Power Plant has been touted for possible conversion to natural gas as the primary fuel source. This conversion could result in significant GHG emissions savings in the short-term as well as reducing air pollution in the city.

Box 9 **CASE STUDY: NAIROBI**

Recently it has been announced that AEP Energy will convert the two diesel-fired Nairobi (Kenya) power plants it's acquiring to gas-fired generators, whose electricity is cleaner and cheaper, the company said. There are few details available at this stage, but this will be a case study to follow up when more information becomes available.

Source: http://northafricapost.com/28903-nairobi-diesel-power-plant-to-be-converted-to-gas-fired-generators.html

5.2.5 Co-benefits of Energy Generation Actions

The uptake of rooftop solar PV and solar water heating could have additional benefits for energy security and access to energy. Locally generated, renewable energy could increase household energy security and protect households from fossil fuel price hikes. This could have potential additional economic benefits through increased disposable income. With less money being spent on energy, more income will be available for other essential and non-essential items, raising overall quality of life. There is, however, the possibility for the rebound effect whereby potential economic benefits from household renewables are not as great as anticipated. For example, the money saved on energy costs could be reduced by an increase in energy use.

In more rural areas, off-grid renewables can provide access to electricity for households which previously had no access. Whilst electrification along the coast has increased to almost 90%, other areas and rural electrification for Guyana as a whole falls below 85% as access to the grid is not economically viable for small, isolated communities (IRENA, 2016, Inter-American Development Bank, 2013). Rooftop solar PV and solar water heating could provide these communities with hot water and a source of electricity (IRENA, 2016).

Switching to renewable energy sources can also have significant environment benefits. It can have air quality benefits from the reduced burning of fossil fuels, leading to health benefits, especially in communities that live near to polluting point sources such as power stations. Health benefits can lead indirectly to economic benefits as an individual will have greater productivity and fewer days of illness.

There are also direct economic benefits through job creation including jobs in manufacturing, construction and maintenance. Between 7.1 and 36.4 jobs can be created per megawatt of capacity through manufacture and installation of solar PV power plants with an addition up to 2.5 jobs created through maintenance of the plant.[14] Whilst the Georgetown solar farms are not likely to be this big, these figures demonstrate the potential for job creation.

There are, however, some potential conflicts which must be carefully considered. For example, solar PV farms require space creating possible conflict over land use. Similarly, some may feel that renewable energy installations are visually intrusive. Highlighting the environmental and economic benefits of these installations could help to alleviate these tensions. Consideration must also be given to the potential adverse impacts of material extraction for low carbon technologies. The adverse environmental impact of metal extraction (for example - cadmium) for solar PV may not occur in Guyana but must be considered.

[14] (Bystricky et al 2010)

5.3 Energy Efficiency

While the most significant opportunities for GHG emissions reductions generally lie within the transport and energy generation sectors for Georgetown, it will also be important to manage energy consumption efficiently. Energy consumption for lighting and cooling are significant in the city and with the discovery of oil and gas and the short-term wealth which will be generated, energy consumption is projected to grow rapidly. This is a critical juncture for Georgetown (and Guyana) as key policy and infrastructure decisions will tie-in energy consumption patterns into the future. Not only could this drive increased GHG emissions, but also effect issues such as energy poverty and energy security.

5.3.1 Street Lighting LED Conversion

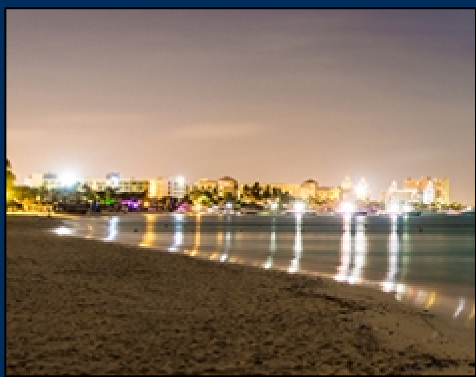
The ongoing improvements to LED lighting technologies and parallel reduction in costs has made it a very economically attractive option for retrofitting older lamps. This is particularly the case with high-output, high-wattage lamps such as those traditionally used for street lighting. All over the world, cities are making the investment to transition to LED street lighting (typically from high- or low-pressure sodium fixtures), which typically offers very short paybacks.

This option is particularly attractive in the context of Georgetown, where the relatively high unit cost of electricity improves the economics further. GPL and the city council have already initiated a programme of switching old fixtures to LED, which has included some pilot fixtures, however the budget available is limiting the speed of the change-out.

With the levels of insolation and sunlight hours available in Georgetown, solar lighting is also a viable option, especially for the installation of new fixtures where connection to the electricity grid could be costly.

Box 10 **CASE STUDY: ARUBA**

Aruba opted for a demonstration for the project in 2012, using 500 of LED Roadway's LED lamps. In 2015, the island converted the rest of its street lamp network and more, using a total of 12,000 fixtures, a contract valued at more than $6 million. It not only replaced all of the island's street lights with the LED technology, but also used the resulting savings from lower energy and maintenance costs to extend the new lamps to about 20 percent of the island that previously had not been lit at night.



Source: https://www.tradecommissioner.gc.ca/canadexport/0002804.aspx?lang=eng

5.3.2 Buildings LED programme

As with streetlighting, there is significant opportunity to convert internal lighting from old incandescent bulbs to LEDs, with typical savings of around 50%. The Guyanese government, GEA and GPL are already actively promoting LED technology. Expanding this promotion and providing the policy framework to support a full transition to LEDs in the residential and commercial sector would accelerate the transition, reducing the energy demand on the grid (i.e. the demand for new generation) while reducing energy poverty and improving energy security.

While tax incentives could encourage some uptake, an outright ban on the import or sale of incandescent and halogen fixtures would rapidly accelerate the transition. CARICOM is currently developing a policy to phase out the import and sale of incandescent fixtures, which Guyana will be subject to.

Box 11 **CASE STUDY: VENEZUELA**

Venezuela began the phase-out of incandescent bulbs in 2005, largely to mitigate a lack of capacity in the national grid. Approximately 45 million bulbs were replaced across 2 years, significantly reducing the national electricity demand and energy costs for the citizens.

Source: https://venezuelanalysis.com/news/4919

5.3.3 Energy Efficient Cooling

Energy demand for cooling is the fastest growing end-use in buildings globally. This is unlikely to be any different in Georgetown as the wealth and quality of life of its citizens continues to grow and climate change continues to increase the frequency of temperature extremes; therefore, demand for cooling will increase exponentially. As a technology, the energy efficiency of air conditioning units varies hugely and is continually improving.

The traditional approach in the buildings of Georgetown appears to be to install small-scale 'spit units' to provide most of the cooling, typically on a room by room basis. The efficiencies of this type of unit varies considerably, with Seasonal Energy Efficiency Ratios (SEER)[15] ranging between 3 and 12.

In order to manage and mitigate the growth of the energy demand on Guyana's national grid, adopting minimum energy performance standards for air conditioning units could have a significant impact and be an effective means of offsetting the cost of new generation facilities.

Box 12 **CASE STUDY: ARGENTINA**

Argentina introduced a minimum energy efficiency ratio of 8 in 2017 as part of a suite of minimum energy performance standards for buildings.

Source: http://www.puntofocal.gov.ar/notific_otros_miembros/bhr397_t.pdf

5.3.4 Co-benefits of Energy Efficiency Actions

Energy efficiency measures can reduce carbon emissions in a cost-effective manner, the energy savings often outweighing initial installation costs. This not only increases energy security but also increases income as less has to be spent on fossil fuels. Guyana is highly dependent on fossil fuel generation for electricity and therefore experiences high electricity costs (Inter-American Development Bank, 2013). Measures such as solar and LED lighting that reduce the need for fossil fuel generation can reduce the amount of expensive, fossil fuel-based electricity that is required.

[15] The SEER is the ratio of useful energy out to electricity consumed, i.e. the higher the ratio the more efficient the unit.

There will also be air quality benefits from energy efficiency measures due to avoided fossil fuel combustion for electricity use. This decreases the amount of harmful air pollutants being released with associated health benefits.

An increased sense of security could be an additional benefit of energy efficiency measures involving lighting. If more areas are well lit at night, people could feel safer being outside when it is dark. This can have positive wellbeing benefits through peace of mind.

Whilst energy efficiency measures have the potential to increase disposable income, these measures must be carefully planned to avoid unintended consequences. For example, LED lights could increase light pollution. Similarly, with cheaper running costs, areas that were previously unlit may become lit and use of lighting may increase overall. This could balance out cost and emissions savings. However, this is not always a negative consequence if it leads to a better quality of life for residents. One planning solution could be to dim the lights by 10% for a few hours after midnight when few people receive the benefits of them. This would minimise energy use and potentially negative environmental impacts.

5.4 Waste

There is currently no waste separation or recycling in Georgetown. It has been estimated that the city generates approximately 68,000 tonnes of municipal solid waste annually, the majority of which is sent to landfill. This approach demands significant space for landfill sites, but also ties the city into long-term GHG emissions as the landfill content decomposes over time. Aside from the GHG emissions and environmental impact, the city is also not maximising its use of resources.

5.4.1 Waste Separation

Waste categorisation and separation is now commonplace in developed cities and becoming more common in developing cities. The environmental and economic benefits of recycling are now well understood and demonstrated around the world.

Guyana's Ministry of Communities has outlined a comprehensive National Solid Waste Management Strategy (NSWMS) which targets recycling or diverting at least 40% of municipal solid waste from landfill by 2024. The Georgetown Mayor and City Council has specific plans to establish a waste separation system, to separate biodegradable and recyclable materials from the waste stream. The plans include provision of a sorting facility and vehicles to provide the collection service, however the financial resources to implement the system have not been identified.

Box 13 **CASE STUDY: BARBADOS**

Barbados has been setting an example on how to manage waste for quite some time now. By implementing the "reduce, reuse, recycle, and recover" policy, Bajans have managed to keep their landfill at 300 tons of municipal waste per day since 1994. The authorities quickly grasped the economic value and foreign exchange earning capacity of waste and have been seeking to maximize it ever since. The key to the success of the recycling program on the island is the Sustainable Barbados Recycling Centre which sorts over 1,000 tons of waste each day.

Source: https://global-recycling.info/archives/2373

5.4.2 Energy from Waste

For non-recyclable materials, there is an opportunity to generate energy from would-be landfilled waste. This reduces the need for landfills and turns waste products into a form of usable energy. The waste can either be incinerated or treated to produce biogas (for example) which in turn is combusted to produce energy.

Plans to develop a waste-to-energy plant have been considered in Georgetown. Proposals to build a plant at the Haags Bosch Sanitary Landfill were considered in 2016, but the facility has not yet been built.

Box 14 **CASE STUDY: JAMAICA**

An Energy from Waste program in Jamaica helps to solve the issues of sustainable waste management and access to clean energy. Organic food waste is collected from hotels and livestock farms and turns it into biogas, which is then converted into affordable electricity to address the needs of communities in Jamaica. Over the next 10 years, there are plans to develop six additional biodigesters in phases, to provide a total of at least 500 kW capacity.

Source: https://www.biogasworld.com/news/renewable-energy-caribbean-development-opportunities-thriving/

5.4.3 Co-benefits of Waste Actions

Waste separation

Action here aims to develop waste separation facilities and collection processes for waste, including recyclable and compost waste. Diverting waste from landfill has environmental benefits through reduced emissions from landfill and economic benefits through reduced landfill costs. There are also larger economic benefits to be had through a decreased use of resources as a result of increased recycling and reuse rates.

Once the facilities and processes are in place, this action could be a relatively cost effective and responsive option. The main ongoing cost would be awareness raising in local communities. This could include education on waste management, wider environmental issues and other capacity building activities.

Energy from waste

The main activity in this section is the building of an energy from waste facility to generate energy from waste that would have been placed in landfill. This could cause a reduction of emissions of greenhouse gases and air quality pollutants through avoided fossil fuel combustion for electricity. Indirect emissions reductions could also happen as energy from waste plants can recover ferrous and non-ferrous metals from waste, therefore decreasing the need for extraction and processing of primary resources (World Energy Council, 2016).

Energy from waste could also reduce costs and increase energy security. With less waste being taken to landfill, landfill costs could be reduced. However, there will still be a cost for handling and processing waste that goes to energy from waste plants. Therefore, this will only be a benefit if the waste handling fee is less than landfill fees (World Energy Council, 2016). The energy generated from waste could provide a lower cost energy source. Combined with a decreased reliance on fossil fuels for electricity this could have energy security benefits, especially at a local level (World Energy Council, 2016).

There is also the potential for employment and education through energy from waste facilities. A waste incineration plant with capacity to process 50,000 tonnes of waste per year would typically employ up to six workers per shift with three shifts every 24 hours (World Energy Council, 2016). Employees at the plant will likely receive training and new plants will often engage with the local community to gain acceptance and educate the local community on the process (World Energy Council, 2016).

There are potential conflicts however that need to be considered before choosing this option. For example, energy from waste plants need to be relatively close to urban areas to reduce the time spent moving waste to the facility; however public opinion is often that they would like the plants to be located further away from cities due to health concerns and other concerns such as aesthetics and traffic. The plant and local authorities will need to work closely with local communities to address these concerns. There could also be a concern that promotion of energy from waste could lead to a decrease in recycling rates, however many countries that currently have 'energy from waste' plants also have high recycling rates (World Energy Council). Public engagement and environmental education could be key to minimising conflicts and maximising benefits.

6 Conclusions and Recommendations

The Mitigation Assessment undertaken for Georgetown provides a series of outputs which can inform the next stage of development for the city. The analysis has shown that many GHG mitigation measures can be implemented with a negative abatement cost over the 20-year timeframe considered. This means that the money saved each year in operational expenditure outweighs the initial capital investment. It is therefore important that CH&PA, the Mayor and City Council and other Ministries involved with the next stage of the City's development take this information into account in any decision making. This will allow the City to follow a low GHG emission pathway at the lowest possible cost, which will also bring associated co-benefits such as reduced air pollution, a more active population leading to health benefits and improved energy security.

In particular, the lowest cost abatement options include solar PV and hot water systems, the conversion of incandescent lightbulbs to LEDs in buildings, optimising the public transport system and cycle lanes, fuel switching at the Kingston power plant and waste separation. In total, Georgetown could reduce roughly 33% of BAU emissions in 2040 at an abatement cost of less than USD 5/tCO_2e, ~~and~~ with much at a negative cost.

In order to further improve the publicity of the information collated and in order to obtain possible technology, financing or capacity building for some of the measures, it is recommended that this assessment is used as the starting point for the development of a NAMA(s) (Nationally Appropriate Mitigation Actions). NAMAs were introduced in the 2007 Bali Action Plan as a key mechanism to increase mitigation actions in developing countries. NAMAs can be policies directed at transformational change within an economic sector, or actions across sectors for a broader national focus. Further information on developing financeable NAMAs can be found in a report produced by the International Institute for Sustainable Development. [16]

In order to improve the basis of the current calculations, the following recommendations are made:

1. The current emissions estimates for 2016 are subject to high levels of uncertainty due to assumptions made in the calculations. Generally, this has occurred throughout the inventory due to limited local data and the subsequent need to scale national data to the Georgetown boundary. This is often the case with the development of City scale GHG emission inventories. However, where possible it would be advantageous to obtain more city specific activity data where possible. Further detail is provided in the GHG inventory report provided in Appendix A.

2. The GHG baseline projections that have been compiled at 5 yearly intervals out to 2040 from the 2016 baseline are based on forecasts of population and GDP growth. Whilst this is likely to provide a good indication of the trend in emissions going forward, ideally sector specific projections would be developed that would be based on expected changes in that particular sector.

3. As with the development of the GHG inventory, in the GHG mitigation assessment, several assumptions have been made. These include the roof area available for solar panels, the composition of municipal solid waste and the number of street lights in Georgetown that could be replaced. Whilst it is thought that good estimates have been made, the cost and emission saving estimates could be improved by using more accurate city specific data on current activity levels.

4. The assessment of GHG mitigation for each measure relies on assumptions about the evolution of the national grid emission factor. There is currently no clear energy policy or projection of the generation mix in Guyana and so assumptions are based on a feasible scenario within the most recent technical study. These assumptions should be updated as and when a clear policy position is

[16] https://www.iisd.org/pdf/2013/developing_financeable_namas.pdf

made. Note the implications of the future energy mix on the electricity price should also be incorporated into the cost calculations.

5. Detailed local cost information was not available for many of the mitigation measures. As a result, the cost results rely on regional case studies where other cities have implemented the measures considered. While this presents currently the best available estimation of capital and operating costs, this should be updated in the future as and when local feasibility studies or project information becomes available.

7 Appendix A: GHG Inventory Methodology

7.1 Introduction

This report provides a greenhouse gas (GHG) emissions inventory for Georgetown, the capital city of Guyana. This inventory will feed in to the development of a GHG roadmap and the development of mitigation options, which will provide the tools and analysis necessary to assess and reduce the emissions arising from Georgetown.

The inventory has been compiled for 2016, the latest year in which data provision was considered appropriate. Methodological approaches have been followed from The Accounting and Reporting Standard for Cities: Global Protocol for Community -scale Greenhouse Gas Emissions Inventories[17] developed by the World Resources Institute (WRI), C40 Cities Climate Leadership Group and ICLEI. Additionally, where appropriate, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[18] have been followed. The following direct GHGs have been considered: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Unfortunately, due to the lack of activity data available, emission estimates for the F-Gases (HFCs, PFCs, SF_6 and NF_3) have not been estimated[19].

The report (along with the accompanying CIRIS tool) provides the direct GHG emission estimates and provides a summary of the approach taken in compiling the emissions inventory. Each sector is discussed in terms of the context, along with a summary of emission estimates and a note on the key assumptions made in compilation, which forms the basis for recommendations for inventory improvement. The following sectors have been considered:

- Stationary Energy (I)
- Transport (II)
- Waste (III)
- Industrial Processes and product use (IPPU) (IV)
- Agriculture, forestry and other land use (AFOLU) (V)

7.1.1 Defining the inventory scope

The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), was developed in order to address the inconsistencies caused by a broad range of inventory methods applied to city scale inventories. By providing a 'robust and clear' framework for calculating and reporting city wide GHG emissions, the protocol allows for the compilation of a comprehensive inventory of emissions occurring within a city boundary. In order to apply the GPC methodology, the scope of the inventory must first be defined. In the case of Georgetown, the geographic scope aligns with the administrative divisions of Guyana meaning the study area is the entire municipality of Georgetown. The GPC also provides a standard for categorizing emissions depending on where emissions arise. This is summarised in Table 2. For the

[17] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
[18] https://www.ipcc-nggip.iges.or.jp/public/2006gl/
[19] These are likely to be minimal. For example, in the EU, they account for less than 2% of GHG emissions (https://ec.europa.eu/clima/policies/f-gas_en). F gases are often used in appliances (such as refrigeration, air conditioning, fire extinguishers and aerosols) as substitutes for stratospheric ozone depleting substances.

Georgetown GHG Inventory, estimates are largely made for Scope 1 only, meaning only emissions physically occurring within the city boundary are accounted for. This is justified in each corresponding sector chapter. In addition, scope 2 (grid electricity) emissions have been provided. Together these form a BASIC GPC inventory. Where possible, estimates have also been made for Scope 3. This is in line with the Basic+ definition of a City inventory under the GPC. The inventory year is 2016, selected as it is the latest year in which data was most widely available.

Table 2 Scopes definitions for city inventories

Scope	Definition
Scope 1	GHG emissions from sources located within the city boundary
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary

Source: Global Protocol for Community Scale GHG inventories – an accounting and reporting standard for Cities.

7.1.2 GHG emission inventory methodology concept

Unless stated otherwise, calculation methodologies referenced in the GPC are consistent with the IPCC Guidelines. Cities are required to estimate GHG emissions by multiplying activity data by an emission factor associated with the activity being measured.

Equation 1: Emission factor approach for calculating GHG emissions.

GHG emissions = activity data * emission factor

Activity data is a quantitative measure of a level of activity that results in GHG emissions taking place during a given period of time (e.g., volume of gas used, kilometres driven, tonnes of solid waste sent to landfill, etc.). An emission factor is a measure of the mass of GHG emissions relative to a unit of activity. For example, estimating CO_2 emissions from the use of electricity involves multiplying data on kilowatt-hours (kWh) of electricity used by the emission factor ($kgCO_2$/kWh) for electricity, which will depend on the technology and type of fuel used to generate the electricity.

Activity data was obtained for the Georgetown inventory from various ministries of Guyana and Georgetown. A full list of data requests made, split by sector and stakeholder, can be found in the Appendix of this report. Where data was not received, estimates have been made or where this has proved too difficult, no estimates have been made. Further information is available in each sector description.

7.1.3 Notation Keys

In GHG emission inventories, notation keys are used to identify data limitations. These are outlined in **Table 3** below.

Table 3 Notation key definitions

Notation key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. That category shall be noted in the explanation
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation
NO	Not Occurring	An activity or process does not occur or exist within the city
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported

Source: 2006 IPCC Guidelines.

7.2 City Inventory Reporting and Information System (CIRIS)

The Georgetown GHG inventory has been compiled using the City Inventory Reporting and Information System (CIRIS). This excel based tool was developed by C40 based on the reporting requirements outlined in the GPC standard. The tool facilitates transparent reporting of all sectors covered by the GPC.

The tool is structured as outlined below:

7.2.1 Introduction

This part of the tool provides the user with instructions on how to use the tab, some introduction to the GPC including sector definitions and scope allocation of emission estimates, notation keys, global warming potential factors (GWP) and conversion factors. All information contained within these tabs are intended to be static and inform the user on key information concerning the inventory.

7.2.2 Set-up

This section of the tool is where user input is first required. It provides space for city information (City name, geographic boundary, climate, population, GDP etc.), lists of data sources and emission factors used in estimates.

The information entered here is fed through the rest of the tool and used in calculations when required.

7.2.3 Inventory

The main body of the tool facilitates the compilation of the inventory. Divided by sector (Stationary energy, transport, waste, IPPU and AFOLU) the separate tabs in the tool allow for the calculation of emissions from user input of activity data, selecting a conversion factor (if appropriate) and an emission factor.

The tool has space for descriptions of methodology and data sources facilitating transparency in calculations.

7.2.4 Calculators

CIRIS includes five in-built calculators to help cities estimate emissions for: fugitive losses from gas distribution; solid waste landfill; biological treatment of waste; waste incineration and wastewater. The calculations are based on IPPC Guidance and use IPCC default factors. These should only be used if no other data is available or otherwise to compare results estimated using another methodology.

7.2.5 Results

The tool summarises the emissions calculated under the inventory section in a few formats. It provides a summary of total city-wide emissions broken down by sector based on the activity data and emission factors submitted. It also enables you to compare your city's current GHG emissions against any historical inventories.

7.2.6 Notes

This section is blank for user notes. Where needed additional information has been added here and linked to the inventory section of the tool. This allows for additional calculations to be performed and documented.

7.3 Stationary Energy

The stationary energy sector covers emissions arising from the following categories:

- Residential buildings
- Commercial and institutional buildings and facilities
- Manufacturing industries and construction
- Energy industries
- Agriculture, forestry and fishing activities
- Fugitive emissions from mining, processing, storage and transportation of coal
- Fugitive emissions from oil and natural gas systems.

The Georgetown inventory includes emissions for Scope 1 (covering emissions from LPG consumption and other fuels occurring in the city) and scope 2 (emissions from grid electricity being generated inside and outside of the City boundary but supplied to the City). A summary of the scope covered is provided below in **Table 4.**

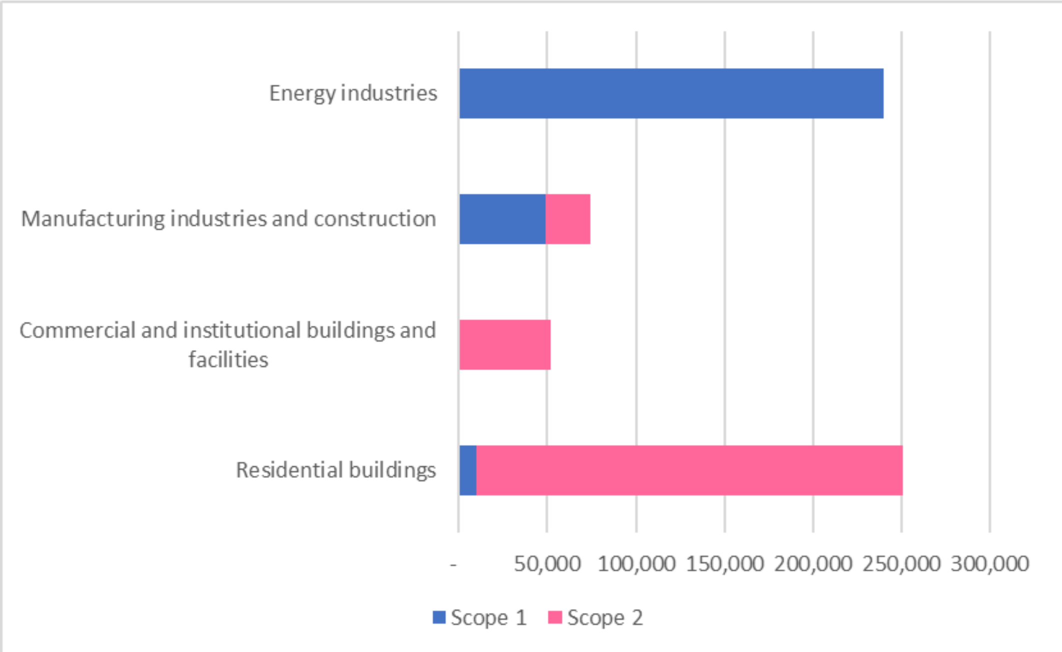
Table 4 Scope of estimated emissions for the stationary energy sector

GHG Emission Source	Scope 1	Scope 2	Scope 3
STATIONARY	Emissions from fuel combustion within the City boundary	Emissions from grid supplied energy consumed within the city boundary	Emissions from transmission and distribution losses from grid-supplied energy consumption
Residential buildings	✓	✓	NE
Commercial and institutional buildings	NE	✓	NE
Manufacturing industries and construction	✓	✓	NE
Energy industries	✓	NE	NE
Agriculture, forestry and fishing	NE	NE	NE
Fugitive emissions from coal and oil and natural gas systems	NO	NO	NO

7.3.1 Emission Estimates

Total emission estimates made for the stationary combustion sector in Georgetown are presented below in Figure 17. There is one power station in Georgetown – Kingston power station. This site runs on heavy fuel oil and gas oil. All other power stations that supply electricity to Georgetown are located outside the City boundary. The emissions arising from the Kingston Power station are included in the emission estimates and it is worth noting that this may therefore lead to a partial double count in emissions. Emissions arising from the agriculture, forestry and fishing sector are thought to be minimal and therefore 'not estimated'. There is no coal production or oil or natural gas distribution systems within the City and therefore emissions for these sectors are reported as 'not occurring'.

Figure 17 Stationary energy sector GHG emission estimates for Georgetown, 2016



Source: Aether; Vivid Economics

7.3.2 Methodology

Residential sector

Emissions in this sector comprise of LPG consumption and grid electricity.

LPG consumption in households. There is no gas network in Georgetown, but LPG cannisters are purchased by households for cooking. Data on the sales of LPG for the whole of Guyana was provided by GEA. This data has been scaled by the proportion of people living in Georgetown compared to the rest of the Country to come up with an estimate of LPG consumption in the City. This data has been combined with default emission factors obtained from the 2006 IPCC Guidelines to generate an estimate of GHG emissions for this sector.

Although the Energy Balance for Guyana identifies households in Guyana as combusting firewood, sugar cane, kerosene, diesel oil, fuel oil and charcoal, it has been assumed that these fuels are only utilised outside of Georgetown, where access to electricity is sometimes limited.

Grid electricity consumed by households. The amount of electricity consumed by households in Georgetown in 2016 was provided by Guyana Power and Light (GPL). This data has been combined with a CO_2 grid electricity factor provided by the Guyana Energy Authority and supplemented with CH_4 and N_2O emission factors from the 2006 IPCC Guidelines.

Commercial and institutional sector

The amount of electricity consumed by the commercial sector and for street lighting in Georgetown in 2016 was provided by Guyana Power and Light (GPL). This data has been combined with a CO_2 grid electricity factor provided by the Guyana Energy Authority and supplemented with CH_4 and N_2O emission factors from the 2006 IPCC Guidelines. No information was available on the amount of fuel directly combusted in this sector and therefore no emission estimate has been made for this source.

Manufacturing Industries and Construction
Data was made available by GPL on the electricity supplied to the industrial sector. However, the data is highly variable year to year and therefore the median value for the 2014 to 2016 time period has been utilised. This therefore leads to uncertainty in the activity data used.

Data was provided by GEA on the amount of different fuels consumed by the industrial sector in Guyana. This included wood, LPG, diesel oil, fuel oil and charcoal. In the absence of other information being available, it has been assumed that 66% of each fuel is combusted in Georgetown.

Energy Industries
Data was provided by GEA on the amount of gas oil, fuel oil and lubricants combusted at the Kingston Power Plant. The data is highly variable year to year and so the average amount of fuel consumed between 2016 and 2018 has been used in the emission estimations. As noted previously, including this aspect in the emission estimates may lead to a partial double count in emissions. The CIRIS tool however includes emissions arising from this sector and also it is important to include this aspect for the mitigation calculations as one of the actions relates to this power plant.

Assumptions and recommendations
Estimating the consumption of LPG in Georgetown is difficult as no data is directly available for the City. This therefore leads to uncertainties in the emission estimates. In addition, limited data was available for the industrial sector. A summary of key assumptions and recommendations is provided in Table 5 below.

Table 5 Assumptions and recommended improvements for the stationary combustion sector

Stationary sub-sector	Assumption	Improvement
LPG consumption in households	Assumption that LPG sold in Guyana can be proportioned using population to Georgetown	The fuel sales method could be improved by obtaining data on fuel sold from city fuel distributors
Electricity combustion in industry	The median value of the consumption between 2014 and 2016 has been used due to a highly variable dataset	That the data is checked to ensure accuracy
Fuel combustion in industry	That 66% of the fuel consumed in the industry sector in Guyana is attributable to Georgetown	Data on fuel consumed in industries within Georgetown is collected
Fuel combusted in Kingston power station	The average amount of fuel consumed over the 2016 to 2018 time period has been used, due to a highly variable dataset	That the data is checked to ensure accuracy

7.4 Transportation

The transportation sector covers city transit via on road transportation, railways, water-borne transportation and aviation. The Georgetown inventory includes emissions for Scope 1 (covering emissions from transportation occurring in the city) and scope 3 (emissions from portion of transboundary journeys occurring outside the city for Road Transportation and aviation only). A summary of the scope covered is provided in Table 6.

Table 6 Scope of estimated emissions for the Transportation sector

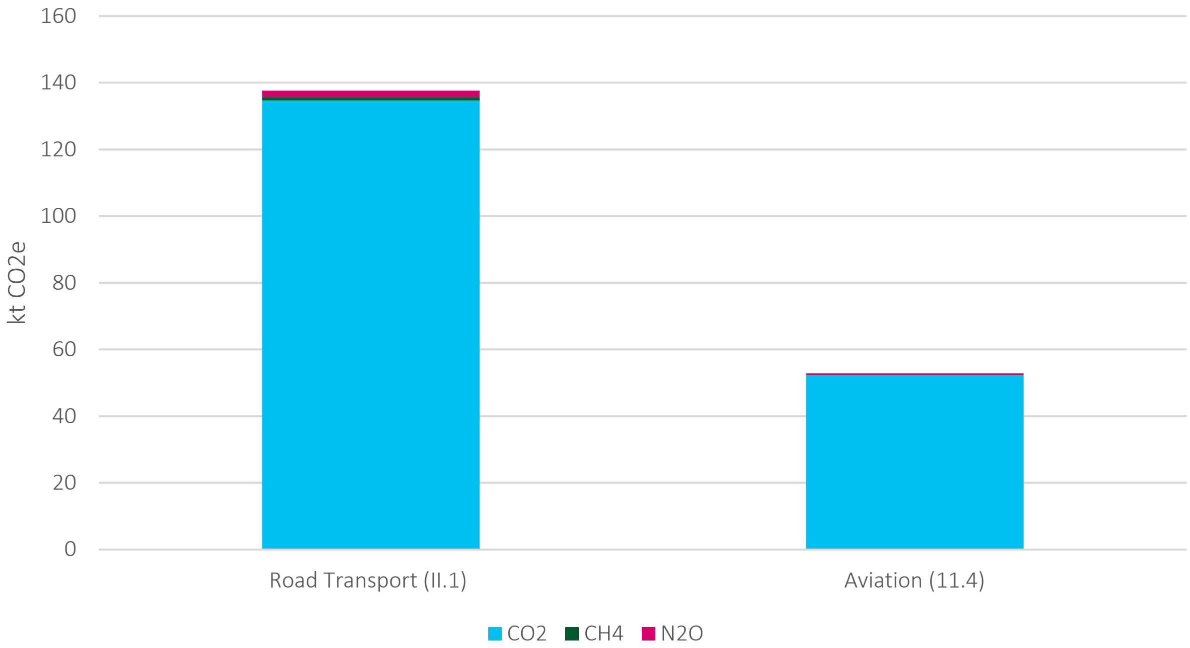
GHG Emission Source	Scope 1	Scope 2	Scope 3
Transportation	Emissions from fuel combustion for transportation occurring in the city	Emissions from consumption of grid supplied energy for in boundary transportation	Emissions from portion of transboundary journeys occurring outside the city, and transmission and distribution losses from grid-supplied energy
On Road Transportation	✓	NO	IE
Railways	NO	NO	NO
Water Transport	NE	NO	NE
Aviation	NO	NO	✓
Off-road transport	NE	NO	NE

7.4.1 Emission estimates

Total emission estimates made for the Transportation sector in Georgetown are presented below in **Figure 11.** There are no railways in Guyana and therefore no emission estimates are provided for this source. In addition, no estimates have been made for water-borne transportation due to a lack of data being available.

Emissions of CO_2, CH_4 and N_2O occur from the combustion of diesel oil and motor gasoline in road vehicles and from jet kerosene in the aviation sector and the results are summarised below. In 2016 in total it was estimated that 138kt and 53 $KtCO_2e$ was emitted by road vehicles and aviation respectively in Georgetown.

Figure 18 Summary of emissions from Transportation (II) in Georgetown



Source: Aether; Vivid Economics

7.4.2 Methodology

Road Transportation (II.1)

The road transportation sub category includes all vehicles which may reasonably be estimated to use the Georgetown road network. This includes vehicles such as buses, cars, trucks, motorcycles, on-road waste collection and transportation vehicles. It is assumed that no electric vehicles are currently in the Georgetown vehicle fleet.

In line with the 2006 IPCC guidelines, emissions of CO_2 are best calculated on the basis of the amount and type of fuel combusted (taken to be equal to the fuel sold) and its carbon content. For estimating CH_4 and N_2O emissions, it is preferable to use the distance travelled by vehicle type, if this information is available. Due to a lack of detailed information on distances travelled by vehicle type, a fuel-based approach has been used to generate all GHG emission estimates. Fuel consumption data was taken from the national energy balance provided by the Guyana Energy Authority and scaled by the fraction of the Guyanese population that lives in Georgetown. This approach has been followed by the majority of city inventory compilers due to fuel consumption data not being available explicitly at the city level for most cities but leads to uncertainties in the emission estimates. The activity data (quantity of fuel sold) has been multiplied by the 2006 IPCC default GHG-emission factors for each gas (CO_2, CH_4, N_2O) to generate emission estimates. These results were sense checked against a bottom up resident activity approach using vehicle registration data and an estimate of the vehicle kilometres travelled and a good agreement was obtained. This bottom up approach will be used in the GHG roadmap to estimate the GHG emission reduction potential of different mitigation options.

Emissions have not been apportioned into in-city and transboundary (Scope 1 and Scope 3) however the method assumes a proportion of transboundary trips.

Railways (II.2)
Railway emissions from Georgetown are reported as 'NO' (not occurring) as no railways are currently operating in Guyana.

Waterborne Navigation (II.3)
Water transportation emissions originate from ships, ferries and boats operating within the city boundary as well as marine-vessels whose journeys originate or end at ports within the city's boundary but travel to destinations outside of the city. However, Scope 1 emissions only includes emissions from direct combustion from fossil fuels which originate and terminate within the city boundary. Therefore, no estimates have been made for Georgetown as all ocean-going waterborne journeys are transboundary[20] and no data is currently available for the City's river transport. Following discussions with the Ministry of Public Infrastructure it is thought however that emissions arising from this source are small. Emissions from this source have therefore been reported as 'NE' (not estimated).

Aviation (II.4)
Emissions from this sector includes emissions from airborne trips occurring within the geographic boundary of the city and emissions from flights departing airports that serve the city.

Scope 1 covers emissions from the direct combustion of fuel for aviation trips which both depart and land within the city boundary. Typically, this would include local flights such as helicopters and training flights. It is assumed that there is no activity of this type occurring in Georgetown and therefore emissions under Scope 1 are reported as 'NO'. Equally emissions under Scope 2 are reported as 'NO' as these include emissions from grid supplied energy consumed at airport facilities, which if occurring would be included under Stationary Energy (I).

Scope 3 emissions includes emissions from departing flights at airports that serve the city, whether the airport is located within the geographic boundary or outside of it. Georgetown has one of the international airports within the study area boundary –Eugene F. Correia International Airport (Ogle) and another international airport outside of the City boundary, Cheddi Jagan International Airport, which also serves the city. Estimates were based on Jet Kerosene values for transport reported under the national energy balance. It has been assumed that 100% of the national Jet Kerosene reported in the Country's energy balance occurs as a result of Georgetown's existence. This may however result in an over-estimate and it is therefore recommended that improved data (such as using annual passenger numbers and information on take offs and landings at each of the airports) is obtained if possible. Default emission factors from the IPCC 2006 Guidebook[21] were applied to the scaled activity data to give emissions.

Off-Road Transportation (II.5)
Emissions from off-road transportation include emissions from vehicles such as all-terrain vehicles, landscaping and construction equipment, tractors, bulldozers, and other off-road recreational vehicles. Emissions from this source are assumed to be included in the road transportation sector as all diesel and gasoline have been assigned to this sector. Emissions have therefore been reported as 'IE' (included elsewhere).

7.4.3 Key Assumptions and recommendations

City transportation emissions pose a challenge to the accuracy of the GHG emission estimates and allocating them requires a number of assumptions. Key assumptions made and recommendations for improvement are given below in Table 7.

[20] Confirmed during a meeting with the Ministry of Public Infrastructure on the 18th October 2018
[21] Table 3.6.4 and Table 3.6.5. Chapter 3 Mobile Combustion, IPCC 2006.

Table 7 Assumptions and recommend improvements for the Transportation sector

Transportation sub-sector	Assumption	Improvement
On Road Transportation (II.1)	Assumption that fuel sold in Guyana from the national energy balance can be proportioned using population to Georgetown	The fuel sales method could be improved by obtaining data on fuel sold from city fuel distributors. Alternatively, a different methodology could be used, which requires accurate vehicle registration data for Georgetown and average distances driven by each vehicle type
Railways (II.2)	Not applicable	Not applicable
Water Transport (II.3)	That emissions arising from boats within the City boundary are negligible and therefore not estimated	That data on fuel sales for this sector is collected
Aviation (II.4)	That all jet kerosene consumed in Guyana can be assigned to Georgetown	Obtain activity data in the form of total real fuel sales, or estimates of fuel loaded onto aircraft by inquiring with airports or airlines.
Off-road transport (II.5)	Off road transport emissions are included under the fuel sold method for On Road Transportation	The results of a survey of annual fuel consumed by off road vehicles could be used to improve estimates

7.5 Waste

Waste generated by cities includes solid waste and wastewater; these may be treated and disposed of in a variety of ways within the city boundary or transported outside for treatment. Emissions of CO_2, CH_4 and N_2O arise from waste from the disposal and treatment methods through processes of aerobic or anaerobic decomposition or incineration. Waste emissions for Georgetown have been estimated from solid waste disposal, open burning and waste water discharge for Scope 1 and Scope 3 (i.e. all waste generated within the city boundary regardless of where it is has been treated).

Table 8 Scope of estimated emissions for the waste sector

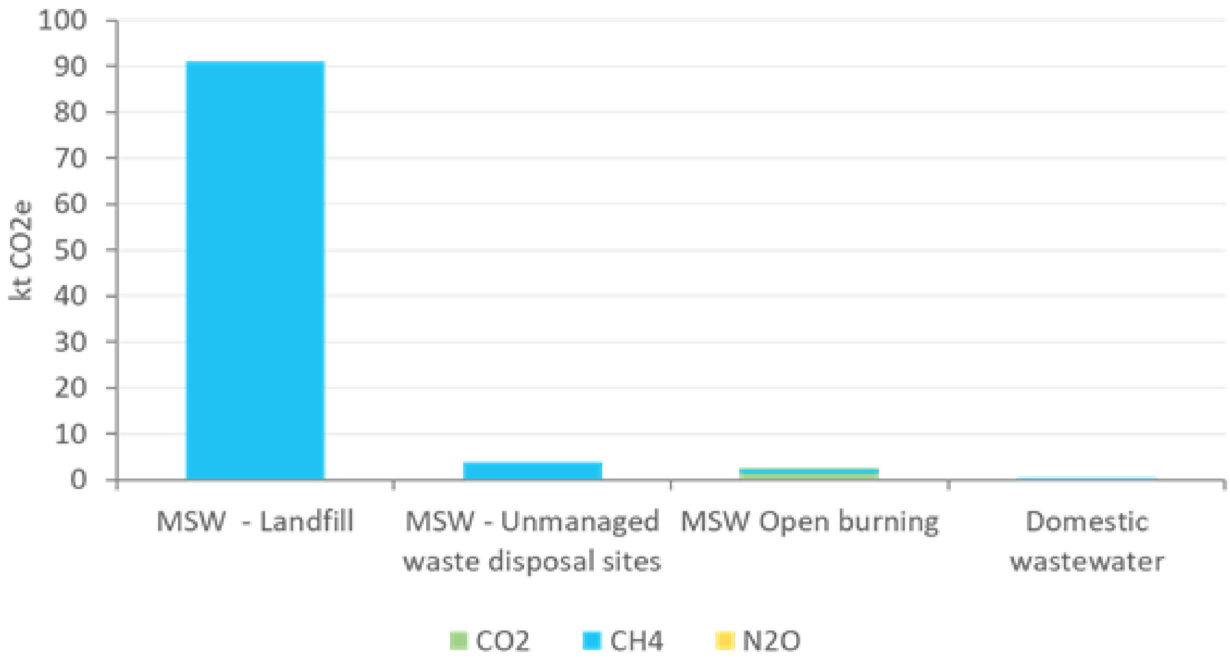
GHG Emission Source	Scope 1	Scope 2	Scope 3
WASTE	Emission from in-boundary water treatment		Emissions from waste generated in the city but treated out-of-boundary
Solid Waste Disposal	✓	-	IE
Biological treatment of	NO	-	NO

waste			
Incineration and open burning	✓	-	IE
Wastewater treatment and discharge	✓	-	IE

7.5.1 Emission estimates

Total emission estimates made for the waste sector in Georgetown are presented below in **Figure 12**. Estimates have been made for CO_2, CH_4 and N_2O from the disposal of municipal solid waste (MSW) and domestic waste water. Total emissions from the waste sector are estimated to be approximately 109kt CO_2e.

Figure 19 Emission estimates from the Waste sector, Georgetown



Source: Aether; Vivid Economics

As expected, the dominant pollutant from the waste sector is CH_4 and this arises from the disposal of MSW in landfill.

7.5.2 Methodology

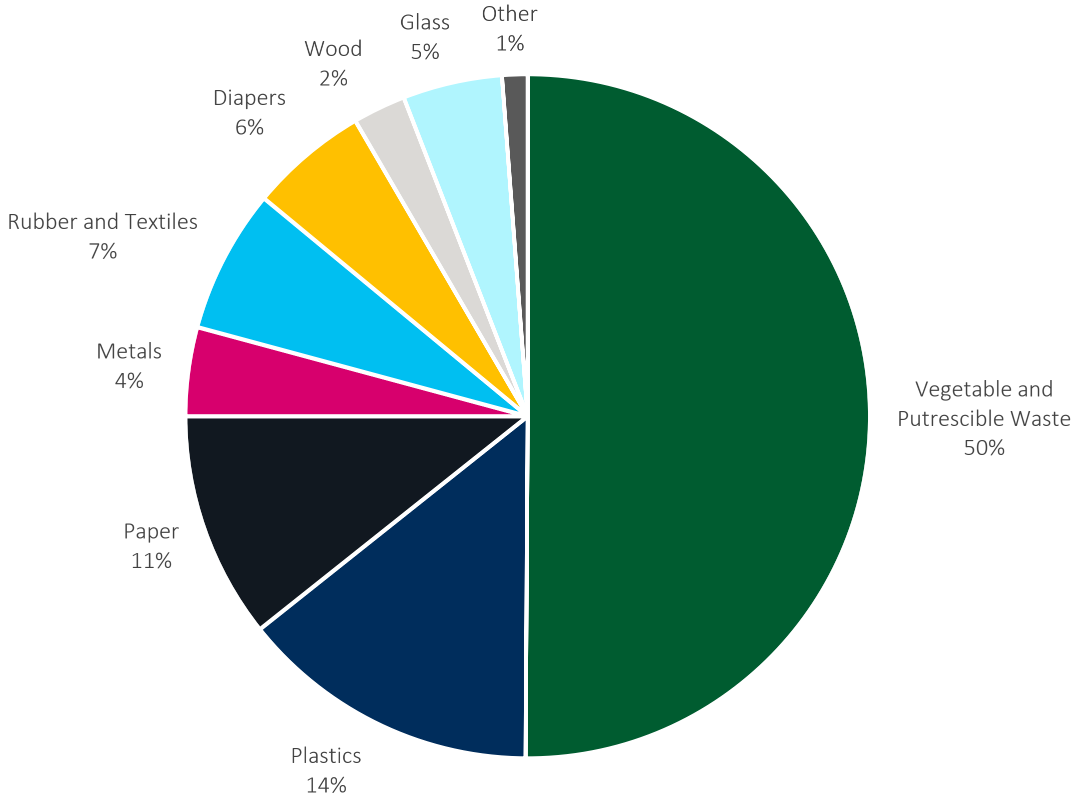
Solid Waste Disposal (III.1)

Emissions of CH_4 arising from solid waste disposal have been estimated for landfill sites and unmanaged waste disposal sites for municipal solid waste (MSW) and industrial waste.

MSW activity data has been taken from the report from the Ministry of Communities entitled 'Putting Waste in its place: A National Integrated Solid Waste Management Strategy for the Cooperative Republic of Guyana 2017-2030[22]'. This reported solid waste generation to be 1.35 kg per capita daily. Using population as a scaling factor per capita generation was used to derive total solid waste generation of 68,221 tonnes/ year for Georgetown. The Ministry of Communities report also provided a summary on the composition of MSW in Region 4 (of which Georgetown is part of). This is illustrated in **Figure 13.** In addition to MSW, the report also reported Industrial Waste for Region 4 which was scaled by population for Georgetown.

[22] Ministry of Communities. Putting Waste in its Place: A National Integrated Solid Waste Management Strategy for the Cooperative Republic of Guyana 2017-2030. Available online: http://www.chpa.gov.gy/images/PDF/GuyanaNSWMS.pdf

Figure 20 Composition of MSW for Region 4, Guyana



Source: Aether; Vivid Economics

To determine emissions arising from the disposal of MSW it is necessary to define the method of disposal for each waste type. The National Waste strategy stated that *"The main waste disposal methods in Guyana are open burning, open dumping and controlled dumping. The largest waste disposal site is the Haags Bosch Sanitary Landfill located in Eccles in Region 4"*. This statement was used to justify the regional assumptions from the 2006 IPCC Guidebook[23] on MSW waste disposal. IPCC defaults suggests that for the Caribbean typically 83% of MSW is disposed of via Solid Waste Disposal Sites (landfill), 2% by incineration and 15% by other unspecified management. There is no incineration of MSW in Georgetown and therefore the following figures were assumed for Georgetown: 83% disposed by landfill and 17% in other management unspecified. Other management was broken down into 8.5% via unmanaged landfill and 8.5% via open burning.

Activity data, proportioned by disposal methods, were applied to methodologies outlined in the GPC. For landfill emissions and unmanaged waste disposal, the methane commitment method was applied. This method assigns landfill emissions based on waste disposed within a given year using a mass-balance approach. This method requires the calculation of a methane generation potential (L0), which specifies the amount of CH_4 generated per tonne of waste. The L0 is a function of the landfill characteristics and the portion of degradable organic carbon (DOC) that is present in solid waste. These values were obtained as default from the IPCC 2006 Guidelines[24]. Higher relative emissions arise from managed landfills where a larger fraction of waste decomposes anaerobically in the layers of waste, therefore emissions from managed landfills dominate the sector.

[23] Table 2.1. MSW Generation and Treatment Data – Regional Defaults, IPCC 2006 Guidebook
[24] Table 2.4 Default Dry Matter Content, DOC Content, Total Carbon content and fossil carbon factors of different MSW components

It is worth noting that the GPC approach results in higher emission estimates (approximately a factor of two) than if the IPCC waste model is used. The GPC model works by assigning the emissions arising in subsequent years from the amount landfilled in 2016, to the 2016 inventory, whereas the IPCC waste model would assign the emissions to the year in which they occur. There are other differences in the methodology used too. Each waste model has its pros and cons and they often show wide variations in their emission estimates. Due to the large uncertainty in the amounts of methane arising from solid waste, no model is deemed to be more accurate than any other[25]. However, when emission estimates are made in future years for the Georgetown waste sector, it is recommended that the GPC approach is used again if an assessment of the trend in emissions wants to be undertaken.

Biological Treatment of Waster (III.2)

There is no reported biological treatment of waste occurring in Georgetown, therefore emissions from this sector are reported as 'NO'. Biological treatment of waste would include emissions arising from composting and anaerobic digestion of organic waste.

Incineration and Open Burning (III.3)

Open burning of waste is an uncontrolled waste disposal method assumed to account for 8.5% of waste disposal in Georgetown. Emissions arising from open burning can be estimated for CH_4, N_2O and CO_2.

Non-biogenic CO_2 emissions are estimated based on the quantify of dry matter waste burnt and the carbon content of the waste, including the fraction of carbon from fossil fuel origin. These values were obtained for each waste type (identified in Figure 4) as default values from the 2006 IPCC Guidebook[6]. Emissions of N_2O and CH_4 were also calculated based on default emission factors from the 2006 IPCC Guidebook.

Wastewater Treatment and Discharge (III.4)

The CIRIS tool has a number of in-built calculators used to estimate emissions with limited data. One of these tools is the Wastewater calculation tool designed to estimate CH_4 and N_2O emissions from the treatment of domestic, commercial and industrial waste water. This uses default factors derived from the IPCC 2006 Guidebook to estimate emissions arising from wastewater based on population. The Guyana Water Authority (GWI) made the following statement about wastewater treatment in Guyana;

"Guyana water Incorporated, GWI currently has 24 sewerage pumping stations that forms a sewerage system within central Georgetown and a septic receiving station at Tucville that receives sewage from a network within the Tucville-Stevedore housing schemes. These two networks stations collect the effluent from a fixed population of approximately 60,000 residents along with a transient population of another 200,000 persons."

Waste water treatment defaults in the tool were overridden into the following waste disposal splits; 43 % into flowing sewers and 57 % into a septic system. This is based on the proportion of the population served by the GWI sewage network; an estimated 43 % using GWI statistic and Georgetown population estimates for 2016.

7.5.3 Assumptions and Recommendations

Table 9 Assumptions and recommended improvements for the waste sector

Waste sub-sector	Assumption	Improvement
Solid Waste Disposal	Default percentage splits of	Obtain percentage splits of waste

[25] https://ghgprotocol.org/sites/default/files/Waste%20Sector%20GHG%20Protocol_Version%205_October%202013_1_0.pdf Annex I – Comparative analysis of the GHG models for landfills.

	waste disposal methods for Georgetown have been assumed based on IPCC defaults	disposal methods for Georgetown
Biological treatment of waste	-	-
Incineration and open burning	The amount of MSW open burnt has been assumed based on IPCC default factors	Obtain Georgetown specific MSW destinations as a percentage split by population
Wastewater treatment and discharge	Assumed wastewater discharge based on population and regional defaults	Obtain statistics on wastewater generation in Georgetown and quantity received by treatment plants

7.6 Industrial Processes and Product Use (IPPU)

GHG emissions can also result from industrial processing and product use. Only emissions resulting from non-energy uses of fossil fuels industrial activities are accounted for under IPPU. Scope 1 emissions are from industrial processes and product uses occurring within the city boundary.

Table 10 Scope of estimated emissions from the IPPU sector

GHG Emission Source	Scope 1	Scope 2	Scope 3
IPPU	Emissions from industrial processes and product use occurring within the city boundary		
Solid Waste Disposal	NE	-	-
Biology treatment of waste	NE	-	-

7.6.1 Assumptions and recommendations

No emission estimates have been made under this sector for Georgetown as it has not been possible to determine if any industrial processes or polluting product use is taking place within the city. Significant emissions sources from this sector are typically from cement production, lime production and glass production. However, Guyana's Second National Communication report confirms (in addition to the meetings held in Georgetown in October 2018) that there is no cement production or other significant industries in Guyana. Therefore, GHG emissions from this source are likely to be minimal.

7.7 AFOLU

City reported emissions from Agriculture, Forestry and Other Land Use (AFOLU) encompass land use changes which alter the composition of the soil, methane produced from livestock and nutrient management for agriculture. Scope 1 emissions include all emissions resulting from the AFOLU sector within the city boundary.

Table 11 Scope of estimated emissions from the AFOLU sector

GHG Emission Source	Scope 1	Scope 2	Scope 3
AFOLU	Emissions from agriculture, forestry and land use occurring within the city boundary		
Livestock	NE	-	-
Land	NE	-	-
Aggregate sources and non-CO_2 emission sources on land	NE	-	-

7.7.1 Assumptions and recommendations

No emission estimates have been made under this sector for Georgetown as no agricultural activity data has been reported. Emissions from this sector, if arising within the city boundary, are likely to be negligible due to the predominantly urban land use.

7.8 GHG Inventory Summary

7.8.1 Total Emissions

Estimates for the GHG Inventory for Georgetown for 2016 are summarised in **Table 12** and **Figure 15**. In total, emissions accounted for in the city are 915 ktCO_2e (including those arising from the Kingston Power station). The largest contributor of emissions is the Stationary Energy sector, which alone accounted for 67% of estimated emissions. Transportation is currently the second largest sector followed by Waste accounting for 21% and 12% of the total emissions respectively.

Based on populations statistics from the 2002 Guyana Census, in which population was reported by Town and Major area[26], and extrapolated using data from the world bank[27] to 2016, per capita emissions are estimated at 6.6 tonnes CO_2e per capita.

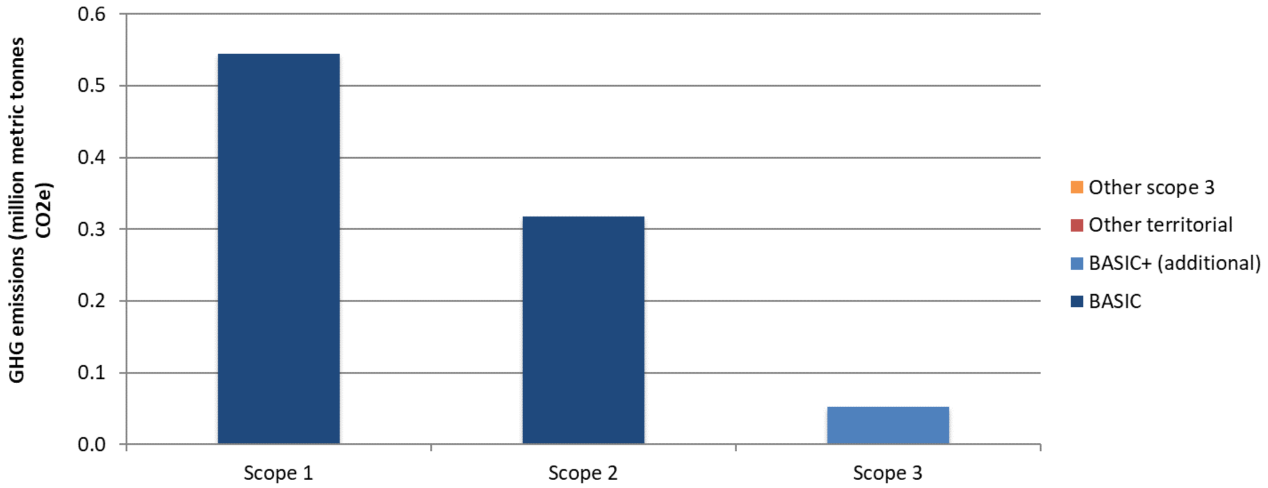
[26] Population by Sex by Town & Major Areas, Town Level Data by population, Statistics Guyana. Available online: http://www.statisticsguyana.gov.gy/pubs/Population_by_Town.zip
[27] The World Bank, Guyana Population statistics. Download at: http://api.worldbank.org/v2/en/country/GUY?downloadformat=excel

Table 12 Summary of emissions estimates for Georgetown, Guyana divided by scape 1,2 and 3.

GPC Basic Inventory GPC Basic+ Inventory

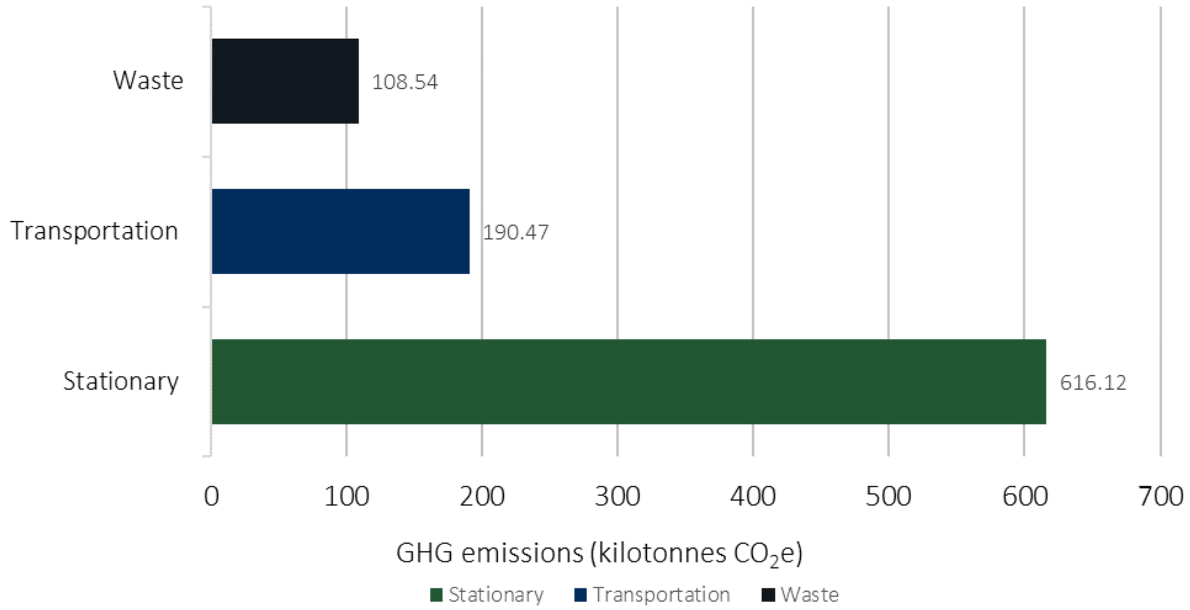
Inventory Sector	Scope 1	Scope 2	Scope 3
Stationary	298,733	317,391	NO
Transportation	137,653	NO	52,818
Waste	108,540		IE
IPPU	NE		
AFOLU	NE		
TOTAL	544,925	317,391	52,818

Figure 21 Summary of Total GHG emissions for Georgetown by scope



Source: Aether; Vivid Economics

Figure 22 Summary of total GHG emissions for Georgetown by inventory sector



Source: Aether; Vivid Economics

7.9 Summary of assumptions

It is important to note that current emissions estimates are subject to high levels of uncertainty due assumptions made in the calculations. Generally, this has occurred throughout the inventory due to limited local data and the subsequent need to scale national data to the Georgetown boundary. This is often the case with the development of City scale GHG emission inventories. Typically, estimates have been made using population statistics as a proxy. Therefore, the crosscutting recommendation for each inventory sector is to obtain data which is specific for Georgetown, where possible.

Developing an inventory is a continuous cycle of improvement, and therefore this report has highlighted where assumptions have been made in each sector and made recommendations for improvements. A summary of assumptions is presented in Table 13.

Table 13 Summary of assumptions made in the GHG emissions inventory

Inventory Sector	Key Assumption
Stationary Energy (I)	LPG sold in Guyana scaled by population. Fuel consumed in the industrial sector estimated to comprise 66% of Guyana's industrial sector as a whole. Electricity consumed by the industrial sector taken to be the average of the 2014 to 2016 time period due to the highly variable annual datasets.
Transportation (II)	National fuel consumption data from the energy balance scaled by population to make estimates for Georgetown for road transport and aviation.
Waste (III)	Per capita Municipal solid waste generation for Region 4 is applicable to Georgetown. Assumed IPCC defaults on waste disposal methods.

IPPU (IV)	No activity in Georgetown
AFOLU (V)	No activity in Georgetown

7.10 GHG Inventory Appendix

CIRIS Report

Full outputs are provided below.

Table 14 GHG emission estimates by scope

GPC ref No.	GHG Emissions Source (By Sector and Sub-sector)	Total GHGs (metric tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
I	STATIONARY ENERGY				
I.1	Residential buildings	10,272	240,369	NE	250,641
I.2	Commercial and institutional buildings and facilities	NE	52,014	NE	52,014
I.3	Manufacturing industries and construction	48,945	25,008	NE	73,952
I.4.1/2/3	Energy industries	239,516		NE	239,516
I.4.4	Energy generation supplied to the grid	NE			
I.5	Agriculture, forestry and fishing activities	NE	NE	NE	
I.6	Non-specified sources	NE	NE	NE	
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal	NE			
I.8	Fugitive emissions from oil and natural gas systems	NE			
SUB-TOTAL	(city induced framework only)	298,733	317,391		616,123
II	TRANSPORTATION				
II.1	On-road transportation	137,653	NO	IE	137,653
II.2	Railways	NO	NO	NO	
II.3	Waterborne navigation	NE	NO	NE	
II.4	Aviation	NO	NO	52,818	52,818
II.5	Off-road transportation	NE	NO	NE	
SUB-TOTAL	(city induced framework only)	137,653		52,818	190,471
III	WASTE				
III.1.1/2	Solid waste generated in the city	95,127		IE	95,127
III.2.1/2	Biological waste generated in the city	NO		NO	
III.3.1/2	Incinerated and burned waste generated in the city	2,611		IE	2,611
III.4.1/2	Wastewater generated in the city	10,802		IE	10,802
III.1.3	Solid waste generated outside the city	NE			
III.2.3	Biological waste generated outside the city	NO			
III.3.3	Incinerated and burned waste generated outside city	NE			
III.4.3	Wastewater generated outside the city	NE			
SUB-TOTAL	(city induced framework only)	108,540			108,540
IV	INDUSTRIAL PROCESSES and PRODUCT USES				
IV.1	Emissions from industrial processes occurring in the city boundary	NE			
IV.2	Emissions from product use occurring within the city boundary	NE			
SUB-TOTAL	(city induced framework only)				
V	AGRICULTURE, FORESTRY and OTHER LAND USE				
V.1	Emissions from livestock	NE			
V.2	Emissions from land	NE			
V.3	Emissions from aggregate sources and non-CO2 emission sources on land	NE			
SUB-TOTAL	(city induced framework only)				
VI	OTHER SCOPE 3				
VI.1	Other Scope 3			NE	
TOTAL	(city induced framework only)	544,925	317,391	52,818	915,134

Source: Aether; Vivid Economics

Table 15 GHG emission estimates by gas

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Notation keys	GHGs (metric tonnes CO_2e)									Explanation for using notation key(s)
				CO_2	CH_4	N_2O					Total tCO_2e		
I		STATIONARY ENERGY											
I.1		Residential buildings											
I.1.1	1	Emissions from fuel combustion within the city boundary		10,247	20	5					10,272		
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary		239,571	237	561					240,369		
I.1.3	3	Transmission and distribution losses from grid-supplied energy	NE										NE due to insufficient data
I.2		Commercial and institutional buildings and facilities											
I.2.1	1	Emissions from fuel combustion within the city boundary	NE										NE due to insufficient data
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary		51,841	51	121					52,014		
I.2.3	3	Transmission and distribution losses from grid-supplied energy	NE										NE due to insufficient data
I.3		Manufacturing industries and construction											
I.3.1	1	Emissions from fuel combustion within the city boundary		41,440	2,615	4,890					48,945		

I.3.2	2	Emissions from grid-supplied energy consumed within the city boundary		24,925	25	58					25,008		
I.3.3	3	Transmission and distribution losses from grid-supplied energy	NE										NE due to insufficient data
I.4		Energy industries											
I.4.1	1	Emissions from energy production used in power plant auxiliary operations within the city		238,733	231	552					239,516		
I.4.2	2	Emissions from grid-supplied energy consumed by energy industries	NE										NE due to insufficient data
I.4.3	3	Emissions from transmission and distribution losses from grid-supplied energy used in power plant auxiliary operations	NE										NE due to insufficient data
I.4.4	1	Emissions from energy generation supplied to the grid	NE										NE due to insufficient data
I.5		Agriculture, forestry and fishing activities											
I.5.1	1	Emissions from fuel combustion within the city boundary	NE										NE due to insufficient data
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	NE										NE due to insufficient data
I.5.3	3	Transmission and distribution losses from grid-supplied energy consumption	NE										NE due to insufficient data
I.6		Non-specified sources											
I.6.1	1	Emissions from fuel combustion	NE										NE due to insufficient data

		within the city boundary											
I.6.2	2	Emissions from grid-supplied energy consumed within the city boundary	NE										NE due to insufficient data
I.6.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	NE										NE due to insufficient data
I.7		Fugitive emissions from mining, processing, storage, and transportation of coal											
I.7.1	1	Fugitive emissions from mining, processing, storage, and transportation of coal within the city boundary	NE										NE due to insufficient data
I.8		Fugitive emissions from oil and natural gas systems											
I.8.1	1	Fugitive emissions from oil and natural gas systems within the city boundary	NE										NE due to insufficient data
II		TRANSPORTATION											
II.1		On-road transportation											
II.1.1	1	Emissions from fuel combustion on-road transportation occurring in the city		134,629	1,075	1,948					137,653		
II.1.2	2	Emissions from grid-supplied energy consumed in the city for on-road transportation	NO										Does not occur
II.1.3	3	Emissions from transboundary journeys occurring outside the city, and T and D losses from grid-supplied energy use	IE										IE as transboundary trips included in II.1.1
II.2		Railways											

II.2.1	1	Emissions from fuel combustion for railway transportation occurring in the city	NO										II.2.1 does not occur
II.2.2	2	Emissions from grid-supplied energy consumed in the city for railways	NO										II.2.2 does not occur
II.2.3	3	Emissions from transboundary journeys occurring outside the city, and T and D losses from grid-supplied energy use	NO										II.2.3 does not occur
II.3		Waterborne navigation											
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring in the city	NE										NE due to insufficient data
II.3.2	2	Emissions from grid-supplied energy consumed in the city for waterborne navigation	NO										II.3.2 does not occur
II.3.3	3	Emissions from transboundary journeys occurring outside the city, and T and D losses from grid-supplied energy use	NE										NE due to insufficient data
II.4		Aviation											
II.4.1	1	Emissions from fuel combustion for aviation occurring in the city	NO										II.4.1 does not occur
II.4.2	2	Emissions from grid-supplied energy consumed in the city for aviation	NO										II.4.2 does not occur
II.4.3	3	Emissions from transboundary journeys occurring outside the city, and T and D losses from grid-supplied energy use		52,291	91	436					52,818		
II.5		Off-road transportation											
II.5.1	1	Emissions from fuel combustion for off-	NE										II.5.1 does not occur

		road transportation occurring in the city											
II.5.2	2	Emissions from grid-supplied energy consumed in the city for off-road transportation	NO										II.5.2 does not occur
II.5.3	3	Emissions from transboundary journeys occurring outside the city, and T and D losses from grid-supplied energy use	NE										NE due to insufficient data
III		WASTE											
III.1		Solid waste disposal											
III.1.1	1	Emissions from solid waste generated in the city and disposed in landfills or open dumps within the city			95,127						95,127		
III.1.2	3	Emissions from solid waste generated in the city but disposed in landfills or open dumps outside the city	IE										IE as emissions from waste generated in the city included under III.1.1
III.1.3	1	Emissions from waste generated outside the city and disposed in landfills or open dumps within the city	NE										NE due to insufficient data
III.2		Biological treatment of waste											
III.2.1	1	Emissions from solid waste generated in the city that is treated biologically in the city	NO										III.2.1 does not occur
III.2.2	3	Emissions from solid waste generated in the city but treated biologically outside of the city	NO										III.2.2 does not occur
III.2.3	1	Emissions from waste generated outside	NO										III.2.3 does not occur

		the city boundary but treated in the city											
III.3		Incineration and open burning											
III.3.1	1	Emissions from waste generated and treated within the city		1,409	942	259					2,611		
III.3.2	3	Emissions from waste generated within but treated outside of the city	IE										IE as emissions as all waste generated in the city included under III.3.1
III.3.3	1	Emissions from waste generated outside the city boundary but treated within the city	NE										NE due to insufficient data
III.4		Wastewater treatment and discharge											
III.4.1	1	Emissions from wastewater generated and treated within the city			432						10,802		
III.4.2	3	Emissions from wastewater generated within but treated outside of the city	IE										IE as all wastewater generated in the city included under III.4.1
III.4.3	1	Emissions from wastewater generated outside the city boundary but treated within the city	NE										NE due to insufficient data
IV		INDUSTRIAL PROCESSES and PRODUCT USES (IPPU)											
IV.1	1	Emissions from industrial processes occurring in the city boundary	NE										NE due to insufficient data
IV.2	1	Emissions from product use occurring within the city boundary	NE										NE due to insufficient data
V		AGRICULTURE, FORESTRY and											

		OTHER LAND USE (AFOLU)											
V.1	1	Emissions from livestock	NE										NE due to insufficient data
V.2	1	Emissions from land	NE										NE due to insufficient data
V.3	1	Emissions from aggregate sources and non-CO2 emission sources on land	NE										NE due to insufficient data

Source: Aether; Vivid Economics

Data Requests

Table 16 Full list of data requests sent for compilation of the inventory

Type	Data	Description	Stakeholder
Municipal Solid Waste	Dump sites	Any data on number and location of dump sites and annual tonnages of waste going to them	MCC
Energy	Electric vehicle strategy	Any data or information on proposed EV pilot roll-out and any longer term EV strategy	GPL/GEA
Energy	Smart Grid Strategy	Any data or information on proposed roll-out of Smart Grid and Smart Meters	GPL
Municipal Solid Waste	Waste to energy	Any details of proposals on waste to energy plants (costs, benefits, amount of waste that would be diverted from landfill etc.)	MCC
Energy	Electricity demand projections	Any future electricity demand projections for Georgetown	GPL
Energy	Future grid emission factor projections	Any future projections of the energy mix and associated GHG emission factor for the national electricity grid	GEA
Energy	Electricity grid emission factor	Average annual grid GHG emission factor (CO2 equivalent) for the most recent 5 years available	GEA
Energy	Electricity consumption from street lighting	Consumption from within the Georgetown administrative boundary for the most recent 5 years available	GPL
Energy	Electricity consumption from buildings	Consumption from within the Georgetown administrative boundary for the most recent 5 years available, broken down by sector (residential, commercial and industrial customers).	GPL

Energy	LPG Consumption/Sales data	Consumption/sales for last 5 years available for the Georgetown area	GEA
Energy	Solar PV installation plans	Data for possible PV installations within the Georgetown administrative boundary	GPL
Energy	Industrial fuel combustion	Data on fuel types and volumes combusted by industry for the most recent 5 years available	GEA
Climate Change	Bartica Mitigation Study Pilot	Description and supporting data for mitigation options being considered for Bartica Pilot	OCC
Climate Change	National GHG mitigation options	Description and supporting data for mitigation options being considered for Third National Communication	OCC
Climate Change	National GHG Inventory	Draft inventory data (excl. LULUCF) and methodology for 3NC	OCC
Climate Change	National GHG projections	Draft projections and methodology for future emissions scenarios (BAU and mitigation) from 3NC	OCC
Climate Change	NAMA for Greening Towns	Draft report and any supporting data sets for draft NAMA	OCC
Energy	Energy balance	Guyana energy balance for last 5 years of available data	GEA
Energy	List of industries	List of industries located in Georgetown and description	MCC
Mitigation general	Low carbon initiatives	List of low carbon initiatives the MCC has discussed or considered	MCC
Water	Sewage water volumes projections	Projections of sewage water volumes for any years available	GWI
Transport	Active transport routes	Proposals or options identified by MoPI for active transport routes in	Transport, MoPI

		Georgetown	
Transport	River transport	Report on modernisation of river transport	Transport, MoPI
Water	Sewage water content	Sewage water content analysis results (breakdown by residential and industrial if possible)	GWI
Water	Sewage water volumes - historic dataset	Sewage water volumes for most recent 5 years available (breakdown by residential and industrial if possible)	GWI
Transport	Vehicle registration	Summarised vehicle registration data for Georgetown for the period 2010 - 2016 broken down by vehicle type	Transport, MoPI
Energy	Existing Solar PV installations	Total known existing PV capacity in the Georgetown administrative boundary for the most recent 5 years available	GPL
Transport	Traffic count	Traffic count data for the city of Georgetown for the most recent 5 years available	Transport, MoPI
Transport	Vehicle registration	Vehicle registration data for Georgetown and nationally broken down by vehicle type for the most recent 5 years available.	GRA
Municipal Solid Waste	Waste stream composition	Waste stream composition for Georgetown for most recent 5 years available	MCC
Municipal Solid Waste	Waste tonnage	Waste tonnage per year for Georgetown for most recent 5 years available	MCC
Municipal Solid Waste	Landfill sites	Year Haags Bosch landfill site opened	MCC

Source: Aether; Vivid Economics

8 Appendix B: Data tables

Table 17 Financial data assumptions for measures

Mitigation measure	Units	Capex per unit (USD 000)	Operational savings per unit per year (USD 000)	Source
Replacing current minibuses for diesel buses	# Diesel buses	499.39	81.55	Capital and operating costs for minibuses taken from Ministry of Public Infrastructure (2016) and for CNG and electric buses taken from Sierra Club (2016). Cost figures adjusted using local fuel and electricity costs.
Replacing current minibuses for CNG buses	# CNG buses	509.80	114.16	
Replacing current minibuses for electric buses	# Electric buses	780.30	155.87	
CNG retrofit for personal use	# Cars retrofitted	2.67	(0.04)	US Department of Energy (2019). Cost figures adjusted using local fuel and electricity costs and assuming 15,160 miles per year for private/public vehicles and 47,200 miles per year for taxis.
EVs for personal use	# Electric vehicles	30.68	0.72	
CNG retrofit for public fleet	# Cars retrofitted	2.67	(0.04)	
EVs for public fleet	# Electric vehicles	30.68	0.72	
CNG retrofit for taxis	# Taxis retrofitted	2.67	(0.24)	
Electric taxis	# Electric taxis	30.68	2.59	
Cycle lanes	# Kms of cycle lane	286.19	66.38	Climate Smart Cities (2014). Adapted from regional costs for 'Development of cycle lanes'.
Rooftop solar PV - Private sector	# PV panels installed	2.14	0.29	Climate Smart Cities (2014). Adapted from regional costs for 'Solar PV for residential'.
Rooftop solar PV - Public sector	# PV panels installed	2.14	0.29	
Rooftop solar water	# Home systems installed	2.67	1.60	Climate Smart Cities (2014). Adapted from regional costs for 'Solar hot water for residential'.
Kingston power plant fuel switch	# MW	211.78	12.90	Climate Smart Cities (2014). Adapted from regional costs for 'Natural gas retrofit'.
Replacing conventional street lights to LED	# Street lights replaced	0.60	0.09	Climate Smart Cities (2014). Adapted from regional costs for 'Street light conversion to LED'.
Replacing conventional street lights to Solar	# Street lights switched	4.98	0.15	Average of costs taken from Greenshine (2018) and

Mitigation measure	Units	Capex per unit (USD 000)	Operational savings per unit per year (USD 000)	Source
LED				LightInUs (2018).
Buildings LED Programme	# Light bulbs	0.05	0.06	Climate Smart Cities (2014). Adapted from regional costs for 'Incandescent light phase out'.
Energy Efficient Cooling (SEER 16)	# AC units	0.61	0.03	Climate Smart Cities (2014). Adapted from regional costs for 'High efficiency air conditioner'.
Energy Efficient Cooling (SEER 26)	# AC units	0.82	0.05	AMS (2016). Consistent with SEER 16 costings.
Waste separation	000 tonnes of waste recycled per year	2,409.44	222.87	Climate Smart Cities (2014). Adapted from regional costs for 'Recycling pant'.
Waste to electricity	000 tonnes of waste incinerated per year	499.74	2.13	Climate Smart Cities (2014). Adapted from regional costs for 'Waste to electricity'.

Note: All figures are in 2018 USD. Where required, original figures were inflated using US CPI.

Table 18 Feasible Scenario – Estimate of GHG savings and abatement costs

Measure	Capex (USD 10^3)	Operational savings (USD 10^3)	GHG Savings 2020 - 2040 (tCO_2e)	Abatement cost (USD / tCO_2e)	GHG Savings 2040 (tCO_2e)
Optimization of Public Transport System	-178,208	488,649	472,030	658	42,912
Converting Private Light Duty Vehicles	-10,302	-1,002	4,910	(2,302)	632
Converting	-1,656	-241	1,060	(1,790)	91

Measure	Capex (USD 10^3)	Operational savings (USD 10^3)	GHG Savings 2020 - 2040 (tCO_2e)	Abatement cost (USD / tCO_2e)	GHG Savings 2040 (tCO_2e)
the Public Vehicle Fleet					
Converting the Taxi fleet	-939	-817	2,423	(725)	214
Bicycle lanes	-5,708	11,970	27,952	224	3,388
Rooftop Solar PV - Private Sector	-242,869	292,366	1,035,215	48	105,871
Rooftop Solar PV - Public Sector	-17,730	25,950	89,737	92	7,155
Rooftop Solar Hot Water	-30,010	138,197	71,197	1,520	8,302
Kingston PP Fuel Switching	-10,009	7,465	674,752	(4)	61,341
Street Lighting LED Conversion	-6,009	10,730	35,383	133	2,390
Buildings LED programme	-12,138	145,693	107,061	1,247	9,783
Energy Efficient Cooling	-38,553	23,126	180,460	(85)	17,058

Measure	Capex (USD 10^3)	Operational savings (USD 10^3)	GHG Savings 2020 - 2040 (tCO_2e)	Abatement cost (USD / tCO_2e)	GHG Savings 2040 (tCO_2e)
Waste separation	-61,777	67,813	520,503	12	37,217
Energy from Waste	-25,095	1,267	1,340,470	(18)	95,847
Total	**-641,005**	**1,211,166**	**4,563,152**	**125**	**392,201**

Table 19 Smart Scenario – Estimate of GHG savings and abatement costs

Measure	Capex (USD 10^3)	Operational savings (USD 10^3)	GHG Savings 2020 - 2040 (tCO_2e)	Abatement cost (USD / tCO_2e)	GHG Savings 2040 (tCO_2e)
Optimization of Public Transport System	-272,768	667,169	717,435	550	65,147
Converting Private Light Duty Vehicles	-112,917	14,927	45,159	(2,170)	7,194
Converting the Public Vehicle Fleet	-19,004	4,627	12,084	(1,190)	1,033
Converting the Taxi fleet	-10,769	9,003	27,707	(64)	2,439
Bicycle lanes	-23,647	49,591	115,800	224	14,036
Rooftop Solar PV - Private Sector	-485,738	584,732	2,070,429	48	211,741
Rooftop Solar PV - Public Sector	-35,461	51,900	179,473	92	14,310
Rooftop Solar Hot Water	-60,286	281,948	143,282	1,547	16,605
Kingston PP Fuel Switching	-10,009	7,465	981,458	(3)	61,341
Street Lighting LED Conversion	-29,457	13,423	50,891	(315)	3,928
Buildings LED programme	-12,138	145,693	107,061	1,247	9,783

Measure	Capex (USD 10^3)	Operational savings (USD 10^3)	GHG Savings 2020 - 2040 (tCO_2e)	Abatement cost (USD / tCO_2e)	GHG Savings 2040 (tCO_2e)
Energy Efficient Cooling	-51,181	37,948	296,140	(45)	27,993
Waste separation	-96,266	92,581	1,041,007	(4)	74,434
Energy from Waste	-50,191	2,533	2,680,939	(18)	191,694
Total	**-1,269,831**	**1,963,540**	**8,468,864**	**82**	**701,678**

9 Appendix C: Forecasting methodology

Overview

Due to the unique context of Georgetown, we undertook original demographic and economic forecasts in addition to the standard ESCI methodology to develop an accurate picture of future land use demand. Currently available long-term projections of Guyana's GDP and population do not take account of the impact of oil. Oil production will transform the structure of the economy, change long term economic and population growth rates as well as national urbanisation trends. Each of these will have material impacts on land use demand in the future. To ensure our results capture the impact of oil on the future of Georgetown, we produced original projections of core variables to 2040 (in line with the three ESCI studies).

The overall objective of this exercise was to better understand the urban pressures Georgetown is likely to face as a result of oil production and inform the three ESCI studies in the following ways:

- **Climate Change Mitigation Assessment**: projections of both economic activity and population growth inform business as usual GHG emission projections;
- **Disaster Risk and Climate Change Vulnerability Assessment**: projections of population growth and urban growth (generated from the Urban Growth Study) impact the exposure maps used to calculate disaster risk;
- **Urban Growth Study**: projections of residential, commercial and industrial land use demand impact the scale of development in all urban growth scenarios.

The methodology forecast five scenarios for future land use demand in Guyana and Georgetown based on the experience of five countries following similarly large and sudden oil discoveries. The methodology below details how we developed this bottom-up forecast for each scenario, starting with the key demographic and economics drivers of land use demand.

Five case-study countries were selected to reflect a range of possible paths that Guyana could take. Broadly, we classify the five countries as following one of two broad models of development (see Table 17):

- **Minimal domestic development:** the development of the oil sector is managed by multinational companies relying heavily on an international workforce based offshore, with minimal links to the domestic economy. Oil is directly exported with little processing. Increased public revenue generates little structural change.
- **Oil state:** the domestic workforce plays a significant role in the development of the oil sector, with high levels of domestic employment in the local area. With government support, Guyana develops significant downstream activities such as a gas landing site and natural gas-fired power plant.

The countries below present a spectrum of development paths within these two poles that Guyana could take as oil production begins in the near future.

Table 17 The projections considered the case of five countries that discovered large reserves of oil

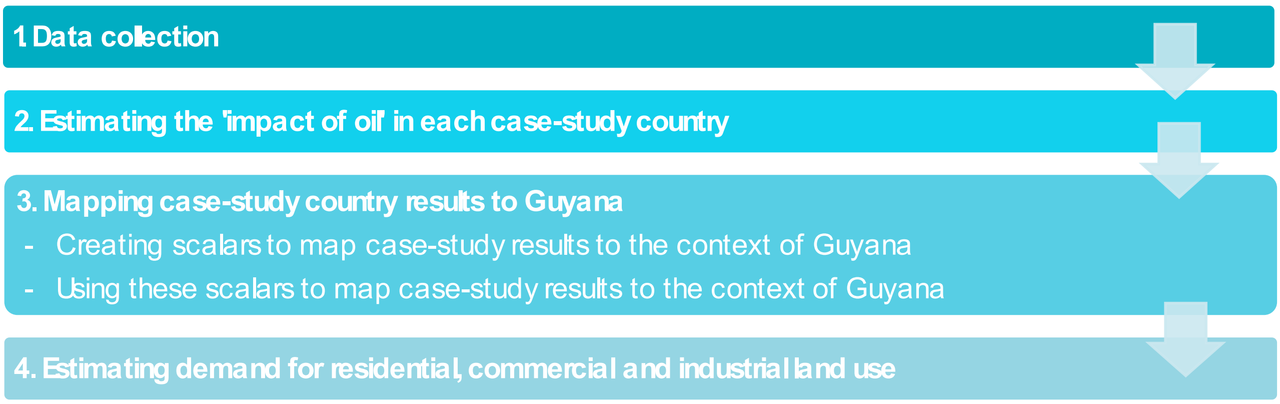
Case-study country	Model of development
Angola	Minimal development
Equatorial Guinea	Minimal development
Ghana	Minimal development

Case-study country	Model of development
Kazakhstan	Oil state
Oman	Oil state

Source: Vivid Economics

To develop estimates for land use demand under an oil scenario for Guyana, we follow four key stages (see Figure 23). Following a data collection phase, we look to estimate the impact that oil discovery has had on five key drivers of land use demand in each of the case-study countries (fertility, mortality, net migration, urban population and GDP growth). We then map each of these impacts to the context of Guyana through the use of scalars that capture the importance of oil in the case-study country relative to Guyana. With projections for the key drivers in Guyana under each case-study country scenario, we then calculate the likely impact on demand for residential, commercial and industrial land use in Georgetown. The following sections explain each step in more detail.

Figure 23 The projections followed a four-step approach



Source: Vivid Economics

Step 1: Data collection

Historical data for each of the case-study countries was compiled to cover a period of 50 years (30 years of data pre-discovery and 20 years of data post-discovery). All historical data and forecasts are sourced from international databases, as discussed below (please see the Urban Growth Study in this series for a full list of sources).

Guyana's non-oil baseline is taken from UN and IMF projections. UN DESA forecasts overall population and its core drivers to 2100.[28] A GDP estimate for the non-oil baseline scenario for Guyana is taken from the 2016 IMF Article IV Report for Guyana, which provides a medium-term real growth rate forecast which does not account for oil production. We assume the forecasted rate (3.8%) remains constant in the non-oil baseline throughout the period.

Strep 2: Estimating the 'impact of oil' in each case-study country

[28] Fertility, mortality, net migration and urban population are forecast to 2100 in 5-year intervals. We use the value given in the data as the mid-point for the 5-year interval and interpolate to create an annual series.

To estimate the impact of oil on the key drivers of land use demand in each case-study country, a hypothetical non-oil baseline trend is first created . The non-oil baseline trend is estimated by extrapolating the pre-discovery trend (looking at the 30-year period before discovery) for each driver. If there is no obvious pre-oil trend then a proxy, such as the regional trend, is used in its place.

Non-oil baselines for the core drivers are then used to calculate non-oil baselines for population and GDP per capita. Non-oil baselines for fertility, mortality and net migration are estimated first and combined to calculate a consistent non-oil baseline for population. Similarly, we estimate real GDP growth under a non-oil baseline and then use this to calculate the evolution of real GDP and then, by combining with population, real GDP per capita.

In contrast to the other demographic drivers, mortality is disaggregated into age-specific rates. We look at three series of mortality by age (0-14, 15-49 and 50+) and create non-oil baselines for each age group separately. This is because trends in overall mortality can be skewed by changes in the age composition of the population over time (as is the case for Guyana, whose ageing population is causing crude mortality to rise).

For each case-study country, we then calculate the 'impact of oil' on each core driver of land use demand. This is calculated by subtracting the historical data from the hypothetical non-oil baseline.

Step 3: Mapping case-study country results to Guyana

Two scalars are used to map the 'impact of oil' onto Guyana:

- **Oil production:** this is calculated as the ratio of the sum of oil production (barrels per day) in the 20 years post-discovery in the case-study country, to the same metric for Guyana. This scalar is used to map the impact of oil on net migration rates, following the logic that the increase in demand for foreign workers will increase in line with the scale of oil production.
- **Oil rents/GDP:** this is the calculated as the ratio of additional oil rents (2010 USD millions) in the 20 years post-discovery divided by GDP (2010 USD millions) at the time of discovery for the case-study country, to the same metric for Guyana. This scalar is used to map the impact of oil on GDP growth, following the logic that the proportional impact on the economy will depend on the size of economic activity in the oil sector relative to the size of the economy before oil production.

The estimates of the 'impact of oil' for each indicator are multiplied by the appropriate scalar to scale down or up the impact of oil in line with the importance of oil in the case-study country compared to Guyana. This gives us oil scenario paths for each of the key drivers of land use demand for Guyana under each case-study.

Due to the nature of fertility and mortality, which cannot reasonably go too high or low, we apply constraints to the maximum change seen over the period. The constraints ensure the series remains in line with UN estimates of Guyana's long-term equilibrium rates. In effect, they cap the maximum reduction in fertility and mortality rates at 60-years further along the UN trajectory. In other words, the impact of oil can accelerate Guyana's progress along this trend by a maximum of 60 years. The constraints are applied to the fertility series and two of the three disaggregated mortality series (0-14 and 15-49). In absolute terms, this is a relatively small change in these indicators as Guyana is already approaching its long-term equilibrium. It is not applied to 50+ mortality rates as it is considered there are still considerable gains to be achieved in the reduction of mortality in the elderly.

The mapping follows the same structure as calculating non-oil baselines, to ensure consistency among our estimates. We first map fertility, age-specific mortality and net migration to the context of Guyana. The three age-specific mortality rates are then aggregated to produce an overall mortality rate. Then fertility, mortality and net migration are combined to reach a consistent population forecast under oil. Urban population is calculated by combining the urban population share with overall population. Finally, GDP is calculated from GDP growth, and GDP per capita is calculated from combining this with population.

Finally, to arrive at a central scenario, we average across the five country case study scenarios. Without a clear view on how Guyana will manage its oil industry and the Government's official policy position, it is sensible to consider the full range of possibilities. Averaging across our range provides an objective and holistic assessment of these.

Step 4: Estimating demand for residential, commercial and industrial land use

As for the drivers of land use demand, we forecast demand for residential land use under each of the five case-study scenarios and then take a central average scenario. These are calculated in the following five stages, for each scenario:

1. **Calculating the national increase in the urban population.** First, we calculate the additional urban population relative to the non-oil baseline using the forecasts generated under Step 3. We then estimate what share of this increase (i) is accounted for by foreign workers and (ii) works offshore. The former allows us to make an assumption about where foreign migrants settle in stage 2 below. The latter allows us to account for workers who reside offshore and do not need onshore housing.

2. **Allocating the additional urban population across cities.** Total urban population is defined as those living in the five largest cities (Georgetown (city and suburb), Linden, New Amsterdam, Anna Regina and Corriverton).[29] First, we assume all foreign migrants settle in Georgetown as it has the most (and highest skilled) economic opportunities compensating the cost of migration. We then allocate the remaining increase in urban population to the five largest cities in proportion to their current share of national urban population.[30]

3. **Translating additional urban population into additional housing units required.** For each city, we use the average household size for its respective region to calculate the additional number of housing units required.

4. **Allocating housing units across density bands.** To gain a more accurate understanding of residential land use demand, it is helpful to differentiate between housing of different densities. We assume that low-, medium- and high- density housing roughly translates to high-, medium- and low-income populations respectively and use occupation distribution in each region as a proxy for income distribution. The proportion of white collar workers is taken as the share of high-income population (low-density housing), the proportion of blue collar workers is taken as the share of medium-income population (medium-density housing) and the proportion of service workers is taken as the share of low-income population (high-density housing).

5. **Calculating additional land use demand in Georgetown.** The additional residential land use area required over the non-oil baseline is calculated by combining the average plot size in low-, medium- and high-density residential areas, as identified from the land use inventory produced as part of the Urban Growth Study, with the number of additional houses demanded. Total residential land use demand is simply the sum across the three densities.

As for residential land use demand, we forecast commercial and industrial land use demand under each of the five case-study scenarios and then take a central average scenario. Demand for commercial and industrial land use is assumed to grow in line with non-oil GDP, that is, the value of economic activity from sectors other than oil. We estimate non-oil GDP by subtracting real oil rents from our forecast of real GDP. The land use inventory (produced under the Urban Growth Study) identifies the current area of commercial and industrial land use in Georgetown. This is then grown in proportion with non-oil GDP under each of the country case-study scenarios. This generates estimates of commercial and industrial land use in each

[29] This definition is aligned with both the UN and the Government of Guyana.
[30] See Appendix 2. The most recent data on city shares of urban population is from the 2012 Census.

scenario out to 2040. The central average scenario forms a key input to business as usual projections of GHG emissions, discussed in Section 3.2.

10 Appendix D: Grid emission factor

Guyana's grid emission factor is a key input to all mitigation measures that displace fossil fuel combustion with electricity. For example, electric vehicles displace the combustion of petrol with the use of electricity. If this electricity is generated primarily from the combustion of heavy fuel oil, there is little (if any) GHG mitigation benefit as heavy fuel oil is as (if not more) carbon intensive than petrol. In contrast, if this electricity is generated primarily from renewables, there is a large GHG mitigation benefit as renewables are carbon neutral.

There is a high level of uncertainty regarding the future of Guyana's energy mix and hence, its grid emission factor. While national media has suggested that natural gas-fired generation will closely follow the production of oil, the Government of Guyana has not yet released an official policy position on this. Furthermore, there is much more uncertainty about the deployment of renewables in the future, especially utility-scale solar and hydropower. Neither the Guyana Energy Agency (GEA) nor the newly formed Department of Energy (under the Ministry of the Presidency) have published an official capacity expansion plan.

Our projections are based on the scenarios presented in 'Guyana's Power Generation System Expansion Study' (Brugman SAS, 2016). This study, undertaken through a partnership between GEA and the IDB, is the most up-to-date economic costing of different power system expansion scenarios. The scenarios explore the most cost-effective energy mix to meet projected national electricity demand allowing for the use of different sets of fuels. Of the scenarios presented, we follow Alternative Scenario III, which allows for the use of liquid fuels, solar, wind, biomass and natural gas. We believe this is the most realistic scenario as both coal and large-scale hydropower are judged unlikely within the timeframe under consideration.

Given the anticipated production of oil, we adjust this projection such that natural gas-fired generation begins in 2025, instead of 2030. Within the System Expansion Study, natural gas is expected to displace all heavy fuel-oil generators in 2030. We judge that developments in Guyana's oil and gas sector since the publication of the study make it more likely this will happen earlier. As a result, we project that natural gas displaces all heavy fuel-oil generators in 2025.

Table 18 below presents the projection used for this analysis.

Table 18 Projected grid emission factor

Fuel share	Unit	2020	2025	2030	2035	2040
HFO / Diesel	%	92%	0%	0%	0%	0%
Natural gas	%	0%	84%	85%	86%	87%
Renewable sources	%	2%	5%	4%	3%	2%
Biomass	%	6%	11%	11%	11%	11%
Grid emission factor	**kg CO_2e / kWh**	**0.81**	**0.42**	**0.43**	**0.43**	**0.43**

Source: Brugman SAS (2016); Vivid Economics

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Contact us

Vivid Economics Limited
163 Eversholt Street
London NW1 1BU
United Kingdom

T: +44 (0)844 8000 254
enquiries@vivideconomics.com